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A SYSTEM DYNAMICS POLICY ANALYSIS
MODEL OF THE AIR FORCE
REPARABLE ASSET SYSTEM

Herbert E. Trichlin, SqnLdr, RAAF
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LSSR 19-81

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The Air Force reparable asset system is an example of a multi-item, multi-echelon inventory system. Though such systems have been extensively studied using classic operations research techniques, there has been little research done on the impact of policy changes on system performance. The system dynamics approach, by focusing on and explicitly representing the information and decision structures of the system under study, provides the means to assess the impact of policy on performance by selecting specific performance goals at each system level. This research developed and validated a descriptive model of the Air Force reparable asset system using a system dynamics approach. Using the DYNAMO simulation language, the impact of policy on the system was demonstrated via computer simulation. The authors concluded that a system dynamics model of the reparable asset system would be of value to Air Force logistics policy-makers.

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A SYSTEM DYNAMICS POLICY ANALYSIS MODEL OF THE AIR FORCE REPARABLE ASSET SYSTEM

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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CHAPTER 1

INTRODUCTION

Background

Military Logistics can be defined in a variety of ways. From a systems standpoint, it may be seen as transforming the output of the nation's defense industry into the nation's defense capability. More specifically, Air Force logistics may be conceptualized as a system that has as its goals the determination of requirements for, and the acquisition, distribution, and conservation of the material and facilities necessary to support the Air Force mission. These goals are achieved through the activities of four major functions: procurement, supply, transportation, and maintenance. Each of these functions is involved to varying degrees in a large number of logistics processes. The reparable asset management process is one of these processes; it is also a key process in the overall system (2:16).

The Air Force manages about 500,000 reparable assets that are components of major systems or subsystems. These assets are dispersed to, and move between, 136 geographically separate operating locations and six central repair and supply facilities. Managing these reparable assets is a challenging and extremely complex task.

The Air Force reparable asset system is an example of a multi-item, multi-echelon inventory system where the base level and depot level constitute the major echelons. As in-use assets become unserviceable, a proportion are repaired at base level. The remainder are returned to a central depot facility where they are repaired and returned to serviceable condition. They are held at depot level until shipped to base level to satisfy a requirement. Day-to-day decisions by key managers in this system impact the requirements and inventory level determination process, the life cycle cost of systems and, ultimately, the operational readiness of weapons systems.

Problem Analysis

There are a number of key issues facing the managers of the reparable asset system. Clark has highlighted a number of these issues and the policy questions they raise (2: 16-27). These issues and questions are shown in Table 1-1.

Analysis of these questions reveals an important fact: few, if any, of these policy questions can be resolved totally within the domain of any one logistics function. For example, the solutions to questions about requirements determination primarily involve supply and inventory policy. These solutions, however, carry implications for the other logistics functions. This is a fairly straightforward example. In the majority of cases these interrelationships are less clear.

Given the size and complexity of the reparable asset processing system, the management problems alluded to by Clark

TABLE 1-1

Reparable Asset System Issues
and Policy Questions [2:22]

Key Issues	Policy Questions
Process Visibility	Information Structure for Management Information Management Responsibility
In Process Inventory Levels	Nonavailability Cost Resource Allocations
Item Essentiality (MRI)	MRI Information Structure Requirements Determination
Reliability Measurement	Engineering Information Structure Life Cycle Asset Management Life Cycle Cost
WRM Requirements	Estimating System (Requirements) Peacetime Operating Policy Requirements Management Structure
Mission Requirements	Determination System Mission Visibility Contract Lead Time Management
Operating & Maintenance Concept	Management Structure - Geographical - Process
Nonavailability	Backorder Cost Policy Inventory Management Policy Stockage/Transportation Inventory Goals
Natural Resource Base	Resupply Base Management

are not unexpected. They are characterisic of complex and dynamic systems in which management has difficulty in determining the real problems that exist or the overall impact of proposed solutions to these problems. Policy decisions often lead to unexpected results. Managers work with a mental picture of the system that focuses on the processes that most affect their area of responsibility. This can lead to incorrect decisions regarding complex systems (13:3-36; 7:117).

Clark has pointed out (2:16-27), and interviews with involved managers at Headquarters Air Force Logistics Command (AFLC) (10; 12) have supported, the fact that it is difficult to predict the impact of policy on the performance of the reparable asset system. Tightened budgets and increasing emphasis on weapons system readiness make it imperative that methods be developed to assess this impact.

Problem Statement

There is a need for a means to analyze the impact of policy changes on the total performance of the Air Force reparable system.

Justification for Research

A number of models are being used to develop Air Force logistics policy. For example, the Optimum Repair Level Analysis (ORLA) Model and Maintenance Manpower Prediction Model are used to make repair level and maintenance manning decisions (4:57-59). However, the majority of research effort

to date has concentrated on developing models of optimum inventory stockage policies as a means of forecasting reparable asset requirements.

The Recoverable Consumption Item Computational System (D041) currently used by AFLC uses simple moving averages of past usage data to compute requirements for reparable assets (16). The D041, taking replacements and repairs into account, determines the quantity and cost of the reparable items which will be required to support the USAF.

Muckstadt and others (7; 17; 26) have approached the analysis of multi-item, multi-level inventory systems from a sophisticated mathematical standpoint. Specifically, the optimum stockage of individual reparable items at different levels within the system are computed by means of an algorithm that minimizes overall expected system backorders. One of these approaches, MOD-METRIC, was used to compute spares stock levels for the F-15 (5:58).

While all of these models are capable of developing quantitatively accurate predictions of optimum spares levels, they share certain limitations. First, they are all based largely on static tools of inventory theory and reliability theory, and deal with the steady-state situation. Thus they neglect real-time response, a crucial dimension in the description of system behavior. Second, because these models have been developed with the objective of developing optimal inventory policy, they have tended to make simplifying assumptions about the other components of the reparable asset

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management system such as maintenance and transportation (11:169).

Logisticians and researchers have not provided an evaluation device that explicitly views the reparable asset system in terms of the interaction of system elements. In this light, Graves and Keilson (11:170-174) have pointed out the value of multi-item, multi-echelon dynamic models of extended logistics systems, and the need for additional research towards developing the tools necessary to study and understand complex system behavior. They go on to define four characteristics that an adequate system model should possess:

1. It should be active (allow for repair and replacement of assets) and dynamic (concerned with the time dependent behavior of the system).

2. It should be sufficiently flexible to accommodate the complexity of multi-item, multi-echelon systems.

3. The model should describe the distribution of persistence times in acceptable and unacceptable system states, that is, the time the system remains in either of these states.

4. Expected system failure times should be available explicitly in terms of underlying parameters.

Clark has expanded on the need for a dynamic model of the reparable asset system and pointed out the value of a policy model to help logistics managers analyze resource system goals (2:59-62). The use of dynamic models to analyze the control and behavior of complex systems is called system dynamics (6:2). Roberts aptly summarizes the basis and

applicability of system dynamics to the analysis of complex systems.

> The system dynamics philosophy rests on a belief that the behavior (or time history) of an organization is principally caused by the organization's structure. The structure includes not only the physical aspects of plant and production process but, more importantly, the policies and traditions, both tangible and intangible, that dominate decision-making in the organization. Such a structural framework contains sources of amplification, time lags, and information feedback similar to those found in complex engineering systems. Engineering and management systems containing these characteristics display complicated response patterns to relatively simple system or input changes. The analysis of large non-linear systems of this sort is a major challenge to even the most experienced control systems engineer; effective and reliable redesign of such a system is still more difficult. The subtleties and complexities in the management area make these problems even more severe. Here the structural orientation of system dynamics provides a beginning for replacing confusion with order [23:4].

Scope

The objective of this research is to develop a policy analysis model for the Air Force reparable asset system. To achieve this objective, the system dynamics analysis techniques developed by Forrester (8) will be used. However, this approach, powerful as it is, cannot produce the ultimate model of a system. For any system, many adequate models are possible, and the choice of one over another depends on the inquiry being pursued (6:19). This is not due to any weakness in the system dynamics approach, but is simply a reflection of the complexity of large systems. Therefore, in order to produce a useful model, a more specific purpose that simply to model the system is required.

In this research, the purpose of the model is to demonstrate the effects of policy and changes within the system on the achievement of the primary goal of the system. Unfortunately the primary goal of the reparable assets system is difficult to ascertain. In general terms the goal of the system is to maintain and sustain a specified level of force readiness commensurate with the available resources of material and manpower. But, what is readiness? How long is implied by sustain? What level of readiness is appropriate? The answers to these questions are determined by operational considerations which themselves are contingent on the circumstances at any time. Furthermore, the answers will not be the same for all the weapons systems supported by the reparable asset system. Consequently, sustaining a given level of readiness is not an appropriate purpose with which to guide the development of our model. That is not to say that readiness is not the goal of the system, just that one cannot develop a useful model around such a variable concept.

On the other hand, from the point of view of system function, it probably does not matter how readiness is defined. The function of the reparable asset system is to process unserviceable assets into serviceable assets and make them available at base level. Therefore, no matter how one defines readiness, a major factor will be the availability of serviceable assets for use at base level. Thus, base level availability will be used as the guiding purpose in developing the initial model in this research.

So far the scope of this research has been narrowed to the development of a model of the Air Force reparable assets system which exhibits total system behavior in response to policy changes or other system disturbances, but in particular, the effect of these disturbances on base level availability of serviceable assets. One further delimitation is necessary. The Air Force reparable asset system supports a number of major defense systems; i.e., aircraft, air defense radars, communication networks, and intercontinental ballistic missiles. Although these systems are comprised of essentially the same technology, their requirements in terms of the response of the reparable asset system are different. To attempt to accommodate these different requirements in an initial model would complicate the model-building task and may mask the impact of significant requirements or implications for a particular system. On this basis it is reasonable to base the initial model on one type of major system. Accordingly, this research will be based on aircraft reparable assets.

Aircraft reparable assets are by far the largest group, and also place the heaviest demands on the reparable asset system in terms of dynamic response. Therefore, by choosing this group as the basis of the model, all the significant variables in the system should be addressed. Hence, the resulting model should be representative of the system in general or, at the most, require only minor changes in order to be applicable to the other reparable asset groups. Accordingly, the following objective was determined for this

research.

Research Objective

The objective of this research is to develop a system dynamics model which demonstrates the effects of policy changes on the availability of serviceable aircraft reparable assets at base level. Subobjectives include to:

1. identify the major processes of the reparable asset system;

2. analyze the elements of those processes, their structure and relationships, and the attributes of the elements and relationships;

3. construct a system dynamics and mathematical model of the reparable asset system;

4. develop a computerized model from the system dynamics and mathematical models of the system;

5. verify the performance of the model and validate that the model represents the system;

6. evaluate the model as a policy development and analysis tool;

7. identify areas of concern for policy makers.

Plan of Presentation

This thesis follows the general outline of the research objective and subobjectives. In Chapter 2 the analytic paradigm followed in this study and the modeling technology used is presented. In Chapter 3 the actual development of the

model is traced from conceptualization through analysis and measurement to eventual computerization. Evaluation of the completed model begins in Chapter 4 where two experiments are performed with the model. The evaluation is completed in Chapter 5 where the sensitivity of the model performance to changes in various parameters is discussed. The final chapter summarizes the research findings and presents recommendations.

CHAPTER 2

METHODOLOGY

Introduction

The Air Force reparable asset system is an example of the complex, highly interrelated systems found in virtually all modern organizations. In the previous chapter the analysis of the reparable asset system and the development of a system dynamics model of the system that could prove useful as a policy analysis tool was proposed. In this chapter the methodology of this research is explained. First, the theoretical framework--the systems science paradigm--of this research is presented. Second, the basics of the modeling technology is presented. Finally, the particular research approach taken in the course of this work is discussed.

The Systems Science Paradigm

Policy analysis and development are essentially futuristic, in that the policies, once implemented, will affect future events in the organization or system. Since the future is always, to some extent, unpredictable, policy decisions must be based on incomplete information. However, the more the policy-maker can understand about how policy affects the system, the better the policy decisions can be. From a systems

viewpoint, then, the goal of any study of policy-making should be adequate knowledge of the whole phenomena rather than accurate knowledge of it. The emphasis in a systems approach to the policy-making problem is to gain knowledge about the impact of policy on the whole system not by observing the parts, but by observing the process of interaction among the parts, and between the parts and the whole (24:288).

To obtain this understanding of systems and their behavior, it is generally conceded that a descriptive approach to system analysis is best. This avoids forcing the system analysis to fit into a preconceived notion of how the system ought to work and permits the investigator to emphasize how the system actually does work. This descriptive approach permits the investigator to capture all the elements of system function, both the concrete, highly quantifiable phenomena and the subtle, qualitative perceptions and pressures that influence how systems react (15:61-77). A particularly useful approach to the study of systems has been the application of the systems science paradigm articulated by Schoderbek, Schoderbek, and Kefalas (24:279-306). The paradigm involves three steps: first, conceptualization of the system; next, analysis and measurement of it; and finally, development of a computerized model.

Conceptualization

The first step in the systems science paradigm is the conceptualization of the system and its processes. The

TABLE 2-1

Input-Process-Output Analytic Framework for Conceptualization Phase

Input	Process	Output
Resources Requirements	Elements Structure Relationships Attributes of Elements and Relationship	Goals Measurement

analysis of each of these processes begin with looking for the goals and major outputs of each process and the requirements for that output. The conceptualization continues with the analyst focusing on the elements of the system involved in each process, their structure and relationships, and the attributes of the elements and their relationships. This analytic framework is represented in Table 2-1 (24:5-22).

The object of the conceptualization phase is to begin to understand the interactions of the system, both internally between the elements and externally between the system and its environment. Because of the complexity of this interaction, the analyst is forced to model these interactions, first at high levels of aggregation and, then, progressively at higher degrees of resolution (24:297). Roberts (23) recommends that modeling begin early, as soon as the analyst begins to collect enough information about the structure and relationships in the system to do so.

These first, structural models of the system usually

take the form of influence or causal-loop diagrams modeled around the basic feedback loops of the system (13:188). To build these causal-loop diagrams, the hypothesized relationship between the elements of the system is specified by considering the elements pairwise. The arrow designates the hypothesized independent-dependent variable relationship, and the "+" or "-" sign the direction of movement expected in the dependent variable. These pairwise relationships are then assembled into cause-and-effect diagrams of the feedback structures of the system.

An example of such a diagram is illustrated in Figure 2-1. In this example the relationships between Flying Hours per Aircraft, the Line Replaceable Unit (LRU) Demand Rate, Serviceable and Unserviceable LRUs, and Serviceable Aircraft are shown. As the number of serviceable aircraft changes, the number of flying hours per aircraft move in the opposite direction, given a constant flying hour program. Likewise, given a constant number of serviceable aircraft, the flying hours per aircraft increase or decrease with increases or decreases in the flying hour program. Changes in the flying hours per aircraft cause similar changes in the LRU demand rate, suggesting the direct relationship between flying hours and demand rate usually observed. As the LRU demand rate increases, the number of unserviceable LRUs increases and the number of serviceable LRUs decreases as might be expected. Finally, changes in the level of serviceable LRUs will cause like changes in the number of serviceable

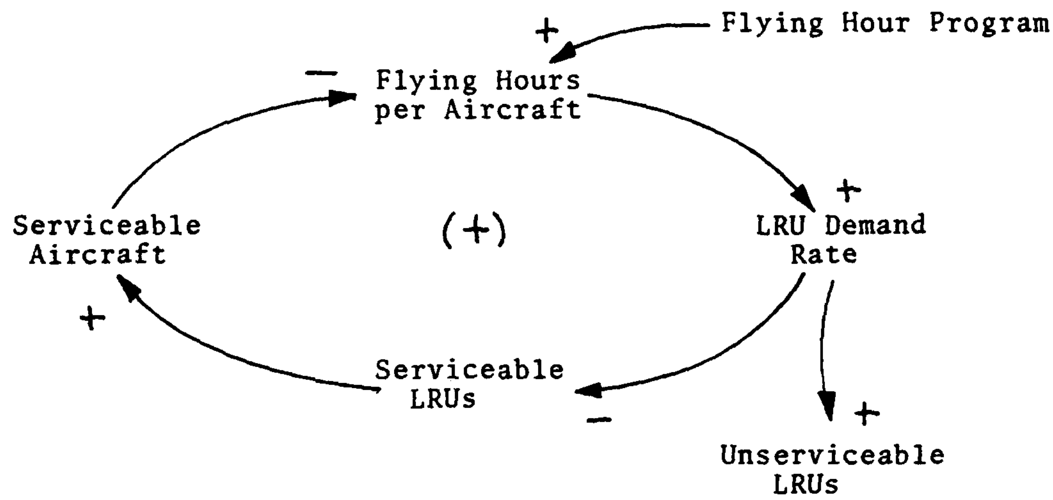


Figure 2-1

Causal-Loop Diagram

aircraft.

Because the linkages in a causal-loop diagram have a polarity ("+" or "-"), each closed path (loop) also has either a positive or negative sign. A causal loop with positive polarity represents a positive feedback path. That is the loop reaction to a change to a variable in the loop is to reinforce that change. This can lead to uncontrollable continuous growth or decline in system response. A system which contains one or more positive feedback loops is potentially unstable. On the other hand, a causal loop of negative polarity represents a negative feedback path. That is the loop reaction to a change to a variable in the loop is to oppose that change. Negative feedback dampens the response of a system to disturbances. Therefore, a system which contains

negative feedback loops is potentially stable. Note in the example in Figure 2-1 that the one loop illustrated is potentially unstable. This follows from the fact that if the flying hours per aircraft are suddenly increased, the LRU demand rate will increase, the level of serviceable LRUs will decrease and, therefore, the number of serviceable aircraft will also decrease. This, in turn, requires more flying hours per aircraft and the cycle repeats until, eventually, all serviceable LRUs are consumed and there are no more serviceable aircraft.

The process of developing the causal-loop diagram provides further definition of the system. Eventually, though, the analyst must begin to develop the analytic material needed to test those hypotheses. This is what goes on in the second step of the systems science paradigm, analysis and measurement.

Analysis and Measurement

In this phase of the paradigm, the hypotheses that came out of the conceptualization are subject to further analysis. There are two major outputs of this phase: a flow diagram and a system of equations to further quantify the nature of the interactions depicted in the flow diagram. The system dynamics approach to this level of modeling provides an excellent technology for the further implementation of the systems science paradigm. This technology and its complementary simulation language DYNAMO will be discussed in the next section of this chapter.

In the analysis and measurement phase of the analysis, the relationships postulated in the conceptualization are broken down further into the flows of material, orders, money, personnel, capital and, most important, information. Furthermore, these flow diagrams permit the analyst to explicitly represent the decision structure that controls these flows by the conversion of the information about system variables into action (8:93-96).

Accompanying these flow diagrams is a set of equations and other mathematical functions that further specify how the system functions on a quantifiable, measureable basis. This mathematical model forms the basis of the last phase of the paradigm, computerization.

Computerization

The final phase of the systems science paradigm is computerization of the mathematical model developed in the previous phase. As noted, the DYNAMO simulation language is specifically designed to help translate that model into a series of first-order difference equations for solution on a high-speed digital computer. This phase of the paradigm provides the analyst with rapid feedback of results from the simulation which aids in determining the aptness of the model (4:186; 13:150). New insights into system behavior may lead to either reconceptualization or to remeasurement or requantification.

Evaluation

Implicit in this last phase of the paradigm is the

evaluation of the computer model of the system that has emerged. Evaluation of large-scale models of complex systems involves at least the following: verification, validation, and sensitivity analysis (6; 20; 25).

Verification. Verification is the process of insuring that the model behaves in the way it was intended to behave (25:210). In other words, this is the verification of the computational sequence. Forrester (8:396-401) provides an excellent example of how the DYNAMO output aids in this process.

Validation. Validation of the model is the process of insuring that model behavior adequately exhibits the behavior of the real system (6:182; 25:29-30). There is a large, judgmental element in determining the adequacy of representation. Unfortunately, there is no definitive answer to this determination. Validation of the model remains the hardest part of the computer simulation (18:309).

While there may be no such thing as the ultimate test of model validity (25:29), there are several criteria which have been proposed. Forrester and others (8; 22) make the point that there are many possible adequate (valid) models for a system, and that the adequacy (validity) of a model depends on whether it serves the purpose for which it was intended. Validity, therefore, is really a question of suitability for intended purpose. On this point Forrester says:

> The validity (or significance) of a model should be judged by its suitability for a particular purpose. A model is sound and defendable if it accomplishes what

is expected of it. This means that validity, as an abstract concept divorced from purpose, has no useful meaning [8:115].

Coyle, writing along the same lines, suggests the following questions be asked about the model in assessing its validity and utility (6:182-184):

1. Is the system boundary right?
2. Are there any gross errors?
3. Is there a correspondence between model structure and the system?
4. Are the parameter values correct?
5. Does the model reproduce system behavior?

Ultimately, as Coyle points out, the best test of confidence is the knowledge that the model has been carefully built up in conjunction with the managers of the system.

The purpose of the model in this research is to demonstrate the effects of policy on the availability of aircraft reparable assets at base level. Validation will be ultimately tested by how well the model achieves this purpose and the correspondence that logistics managers perceive between the model and the system.

Sensitivity Analysis. Once relative confidence has been built in the model, the ultimate evaluation is what Pugh (21:1-15, 118-120) has called in-practice evaluation. That is, how useful is the model for its proposed purpose and how much does it reveal about the behavior of the system. Sensitivity analysis accomplishes this. Simply put, sensitivity analysis involves making changes to parameters and/or structures

in the model and seeing what effect they have on performance (8:196). Without validation this might just be an exercise in model use. But if the analyst has built up confidence in the validity of the model, then the results of sensitivity analysis allow the analyst to infer what policy changes might have the most effect, good and bad, on the real system. Further, sensitivity analysis suggests that those parameters and the model structures that depend on them should receive further attention in studies aiming at advancing the development and sophistication of the model.

So far this chapter has contained a description of the theoretical basis of the proposed system dynamics model of the Air Force reparable asset system. The next section will take up the technology of system dynamics.

System Dynamics

The system dynamics approach and its complementary simulation language, DYNAMO (8), are particularly well suited to the implementation of the systems science paradigm in the study and modeling of the behavior of complex systems (4:150; 13:186). This approach has been successfully used in a variety of studies (1; 3; 4; 6; 8; 13; 14; 21).

As the modeling simulation package adopted for this research, system dynamics and DYNAMO offer a number of advantages (13:186):

1. They provide a direct correspondence between the cause-and-effect conceptualization of the real system, the

model flow diagram, and the computer simulation program.

2. The system dynamics flow diagram is an excellent means of communication between researchers and managers of the system under study. This increases the value of the approach to policy-makers because their understanding of the system is increased in the modeling process.

3. The DYNAMO simulation language is easy to learn. This allows researchers to concentrate on system conceptualization rather than computer programming problems. Further, it does not require the mathematical sophistication needed to use other simulation techniques.

4. DYNAMO provides rapid feedback of results from the simulation program. This rapid feedback aids researchers during model development because it permits evaluation of the aptness of the emerging model and provides clues to what changes will improve the correspondence between the model and the real system.

5. Once the valid model has been developed, this ease of use and rapid feedback enables policy analysts to assess a variety of options without extensive reprogramming of the model.

The purpose of this section is not to provide a primer on system dynamics or DYNAMO. A variety of excellent texts are available on this subject (6; 8; 9; 10; 20). However, some familiarity with flow chart symbols and the DYNAMO simulation language is required in order to completely follow the discussions in the remainder of this chapter and those which follow. The following sections provide that basic familiarity.

System Dynamics Flow Diagrams

System dynamics conceives systems as networks of levels and flows between levels which are interconnected by the flow of information. This conceptualization is represented in a flow diagram. Figure 2-2 lists the principle symbols used in these diagrams; a brief explanation of each symbol follows.

Levels. Levels are the accumulation variables in the system, they represent measureable quantities which will maintain their value if all activity in the system is stopped. Inventories are obvious example of levels within the reparable asset system.

Flows. Flows represent the transfer of quantities or information within the system.

Rates. Rates are the variables which control the flows in the system. The flow of information is an exception. Information flow is a transfer process which relates the variables in the system and, therefore, does not possess a rate of flow quality. It can, however, be delayed; this is discussed under DYNAMO functions.

Source or Sink. This symbol represents the origin or destination of flows from outside the system, or the creation and termination of flows within the system. The creation of a flow of orders and the termination of this flow as orders are filled provides a good example of the latter category of use.

Auxiliary Variables. These variables enable the segmentation of complex interrelationships. The symbol allows

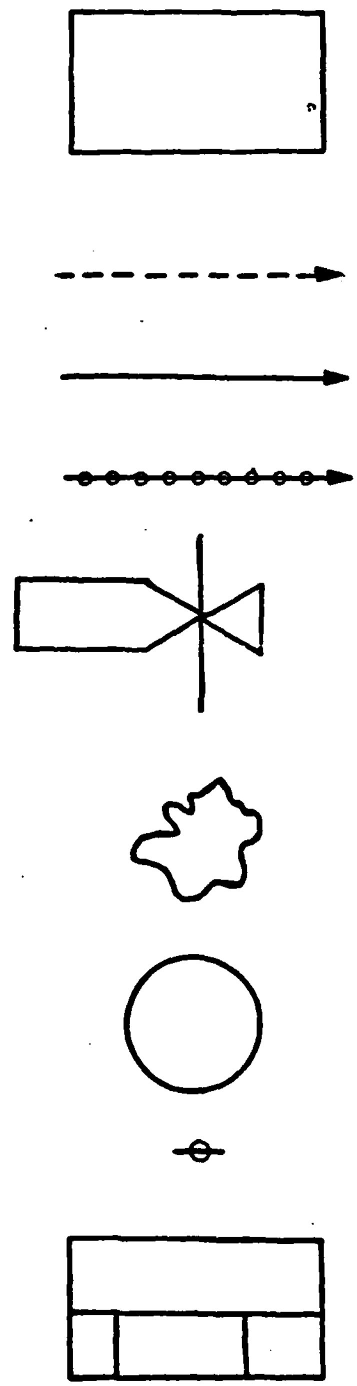


Figure 2-2

Flow Diagraming Symbols

this segmentation to be represented in the system flow diagram. Thus the correspondence between the system, the diagram, and the system of mathematical equations is maintained.

Constants. This symbol represents system parameters which do not change with time.

Delays. Delays account for a significant proportion of the dynamic response of systems. They are used to represent the response lag between changes in one part of the system and the effects of these changes in other parts of the system. Delays are a special form of level in that they store the difference between the input and output flows at any time. For example, if the input rate to a delay increases, then because of the response lag provided by the delay, the output rate will not increase immediately. Until the output rate does respond and eventually increases to be equal with the input rate, the delay stores the difference between the flow rates. The foregoing describes the action of a material delay, and shows that material delays are conservative in that they do not affect the total quantity of material in the system. Material delays simply delay the transfer of material within the system. Information delays, although represented by the same symbol, are nonconservative. This will be discussed further under DYNAMO macros.

System of DYNAMO Functions

The system dynamics flow diagram represents a system of mathematical interrelationships which can be directly

translated into a system of DYNAMO equations. This system of equations comprises rate (R), level (L), initial value (N), auxiliary (A), and supplementary (S) equations. The meaning of rate, level, and auxiliary equations is self-evident. Initial value equations enable the model variables to be initialized as required. The supplementary equations enable quantities of interest to the model-user, but not used by the model, to be computed and included in the output of the model.

Solution Interval. The basic tool of continuous simulation is integration (20:2). Integration relates a quantity to the time rate of change of that quantity. Consider the relationship between a level and the inflow rate to the level. The change in level over any interval of time is given by the integration of the function for the input rate over that interval. This interval is referred to as the solution interval. If the input rate is constant over the solution interval, the solution of the integration is simply the product of the rate and the length of the interval. If, however, the rate is changing over the interval, the solution is much more complex. This complexity is avoided by the DYNAMO language by using approximate integration. In approximate integration, the solution interval is chosen so that the error introduced by assuming that the rate is constant over the solution interval is negligible. Approximate integration is implemented in DYNAMO by the use of J, K and L time subscripts. The subscript J represents the beginning of the previous solution interval, K represents the present, and L the end of the

next solution interval. Using these subscripts and denoting the solution interval by DT, it can be seen that the above level and rate example can be represented as:

$$LEVEL.K = LEVEL.J + RATE.JK * DT$$

where RATE.JK means the value of RATE over the solution interval from time J (the beginning of the solution interval) to time K (the present). The choice of the appropriate solution interval for a model is determined by the length of the delays in the system. This is discussed under DYNAMO macros.

Computational Sequence. In a system dynamics model the values for rates are derived only from information about the levels in the model. This is a consequence of the fact that in reality the instantaneous value of a rate cannot be measured; to determine a rate only an average value over an interval of time can ever be measured (8:77). Therefore, rates cannot in principle be used to determine the value of other rates. Although at times the value of a rate from the JK solution interval can be used if the introduction of an averaging level into the model, although correct, would not significantly improve the accuracy of the results. Because information about levels is used to determine rates, and this information is manipulated by using auxiliary variables, DYNAMO employs the following computational sequence. First all level equations are computed (as shown in the previous example, these equations use the JK values for rates), then the auxiliary equations are computed followed by any supplementaries, and

finally the rate equations are computed. The values obtained for the rates then become the JK values in the next computational sequence. In this way time is advanced in the model one solution interval at a time.

DYNAMO Macros

In writing the equations for a model, certain combinations of equations are used repeatedly. To ease the burden of equation writing, DYNAMO provides these groups of equations as macros which are implemented by simply using the name of the macro. The user may also specify his own macros as required. A brief explanation of each of the macros used in this research follows.

The FIFGE Macro. The FIFGE macro has four arguments (P, Q, R, S). It returns the value of the first argument (P) if the third argument (R) is greater than or equal to the fourth argument (S), otherwise it returns the value of the second argument.

The FIFZE Macro. The FIFZE macro has three arguments (P, Q, R). It returns the value of the first (P) if the third (R) is zero, otherwise it returns the value of Q.

The MAX and MIN Macros. The MAX and MIN macros have two arguments (P, Q), and return the greater or lesser of the two respectively.

The Delay Macros. DYNAMO provides four delay macros, DELAY1, DELAY3, SMOOTH, and DLINF3. The DELAY macros represent first and third order exponential delays respectively. These

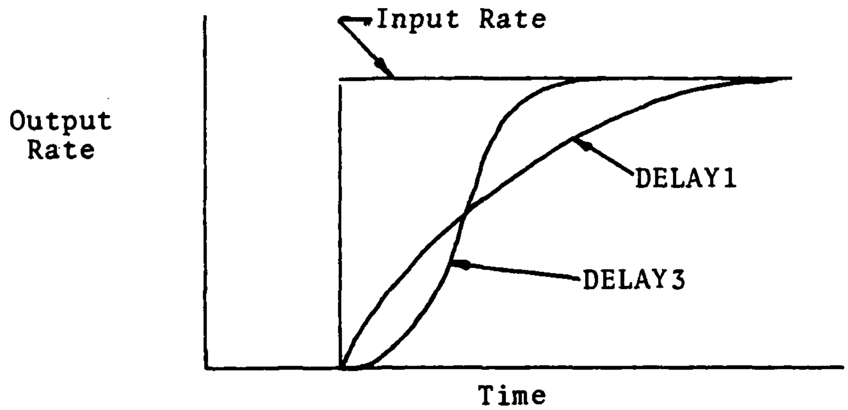


Figure 2-3

Exponential Delay Response to
a Step Change

macros can be used to represent many of the delay phenomena in real systems (8:87). Figure 2-3 shows the time response of these macros to a sudden increase in the input rate (a step change in the input). The initial text by Forrester (8) still provides the best discussion of the validity of using exponential delays and their response characteristics.

The SMOOTH and DLINF3 macros are similar to DELAYI and DELAY3 respectively in that they provide first and third order exponential information delays. The difference is that they are non-conservative structures. That is, they do not accumulate the difference between the input and output rate as must be done by a material delay; they provide the desired response by a process similar to exponential smoothing, as it is used in forecasting.

DYNAMO Functions

To facilitate model building and experimentation with a model, DYNAMO provides a range of functions which can be used to represent time-varying processes in a model or as time-varying inputs to a model. Only the functions employed in this research are described here.

The NORMRN Function. This function provides a normal random variate with a specified mean and standard deviation.

The NOISE Function. This function provides a uniform random variate in the range -0.5 to +0.5.

The SAMPLE Function. This function has three arguments. The first argument is the variable to be sampled, the second argument is the interval between samples (this may be a variable), and the final argument is the initial value returned by the function.

The STEP Function. This function provides a step change of a specified height at a specified time.

The RAMP Function. This RAMP function provides a linearly increasing variable of specified slope which activates at a specified time.

The SUMV Function. The SUMV function sums the specified elements of a vector variable (DYNAMO provides an array capability which can accommodate up to three dimensions for variables).

The SHIFTL Function. The SHIFTL function shifts the contents of a vector variable forward by one element, sets the first element to zero, and returns the value of the last

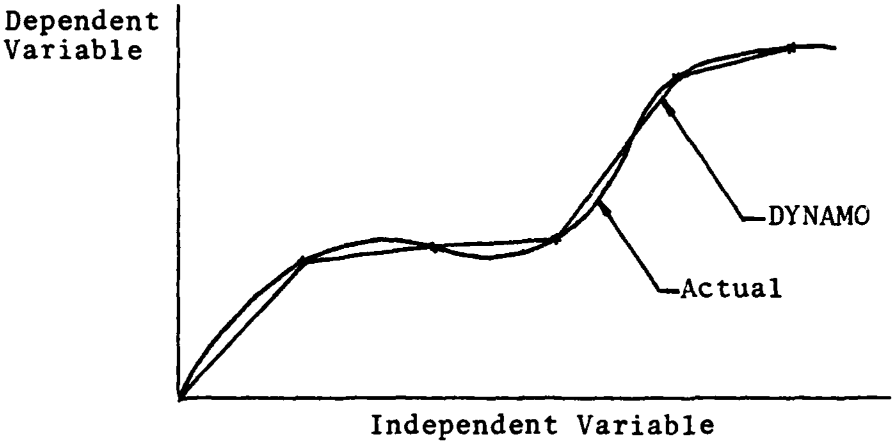


Figure 2-4

DYNAMO Table Function Straight Line Approximation

element prior to the shift.

Table Functions

There are many instances in modeling where the need arises to include a non-linear, or non-simple, relationship between two variables. To facilitate the incorporation of these relationships, DYNAMO provides a table function facility. The DYNAMO table functions enable the user to incorporate a straight line approximation of the desired relationship. Figure 2-4 illustrates such a relationship and the DYNAMO table function straight line approximation for it. It can be seen that the shorter the approximation interval, the closer will be the table function representation to the actual relationship.

Choice of Solution Interval

As discussed previously, the length of the solution interval (DT) determines the accuracy of the results because rates in the model are assumed constant during the solution interval, whereas the actual rates they represent may be continuously changing. If, however, the solution interval is made small enough, the errors due to assuming constant rates become negligibly small. Obviously, the smaller the solution interval the better, but there are practical limits. The computer can accommodate extremely short solution intervals, so computer computational resolution is not the limiting factor; the limiting factor is computer time. At each of the solution points in a run of a model, the computer must make a large number of transactions, many more than the equations of the model may suggest because each equation represents many transactions and each macro used adds a number of equations to the model. Therefore, even a relatively small model may take an inordinate amount of time to run for any reasonable simulation period. A compromise must be made, therefore, between accuracy and run time. A good first choice for DT in most instances is half the shortest first-order delay in the model, or one-sixth the shortest third-order delay, whichever is the least (20:44).

This concludes the discussion of system dynamics and DYNAMO. This discussion should enable the reader without access to the referenced texts to follow the presentation of this research. The following section presents the research approach adopted for this study.

Research Approach

The previous sections of this chapter present the theoretical and technological basis for this research. This final section presents the research approach which was developed from that basis. This approach involves four principle areas: the scope of the model, the selection of a basis for the model, the selection of the unit of time for the model, and the actual methodology of model development. The methodology of model development encompasses most of the research approach. The implementation of this methodology, however, relies on the choices made for model scope, basis, and time unit. Therefore, these choices are discussed first.

Scope of the Model

The reparable asset system can be conceived as consisting of a number of layers with each layer containing the principle system elements, reparable asset employment, maintenance, transportation and storage. Between these layers there is competition for scarce resources. Therefore, a comprehensive model of the reparable asset system would need to represent this multi-layered nature of the system. Such a comprehensive model was beyond the scope of this research.

The purpose of this research was to develop a policy analysis model of the reparable asset system. This does not imply that the model must address all aspects of policy. An initial model which addressed a large part of reparable asset management policy satisfies this objective. A model which

represented one layer of the reparable asset system would capture most of the principle policy issues. Excepted would be the competition between users for scarce resources. Therefore, the scope of the model developed by this research was limited to a single-layer representation. The details of this representation are developed in Chapter 3. The following discussion deals with the choice of a quantity basis for this single-layer representation.

Selection of Model Basis

A system dynamics model represents a system as the flow of some quantity in a network of levels, rates and information. The nature of the flow quantity provides the basis for the model. There are two choices for the nature of the flow quantity. The flow quantity can represent an aggregated flow of a number of different types of a quantity, or it can represent a flow of just one of the types of a quantity. In terms of the reparable asset system, this means that the model may be based on an aggregated flow of reparable assets or on the flow of a particular type of reparable asset. The distinction between these choices will become more apparent in the following chapter as the development of the model is traced. For now it is sufficient to note that each represents a distinctly different basis for the development of a system dynamics model. Neither basis is inherently better than the other, but depending on the purpose of the model, one may be more appropriate than the other.

For this research a particular type of reparable asset was chosen as the more appropriate basis for the model because even though the policy of the reparable asset management system is framed to cover reparable assets in aggregate, this policy is implemented through a complex single-item management and accounting system. This is particularly so for high cost, mission-critical items. Furthermore, each level of management in the reparable asset system has multiple criteria for the management of reparable assets. These criteria are not always fully transferrable between management levels. Therefore, in order to obtain a model which is useful at all levels of policy-making in the reparable asset system, a particular type of reparable asset was considered to provide the most appropriate basis for the model developed in this research. Having made this decision, the choice of a representative reparable asset must be made. Before discussing this choice, however, a clear definition is required of what is meant by the term reparable asset as it is used in this research.

Many terms are in current use to convey the idea of a reparable asset. Some of the more common terms are reparable spares, investment spares, recoverable items and, simply, reparables. All terms convey to some degree the permanence, importance and recycleable nature of these items. For the purposes of this research, a reparable asset is defined as a major component of a weapon system that can be removed, repaired, and reinstalled by base level maintenance personnel, but requiring depot repair for the correction of some faults.

This definition of a reparable asset closely fits the current concept of a Line Replaceable Unit (LRU), and consequently, to avoid possible confusion with other types of reparable assets, this research will use the term Line Replaceable Unit unless a general reference to all types of reparable assets is intended.

In summary, then, this research chose a particular type of reparable asset, a line replaceable unit (LRU), as the basis for model development. Once this choice was made, it was necessary to choose an LRU which was representative of reparable asset policy.

The selection of a representative LRU was made on the basis of the following criteria:

1. The LRU should be mission critical. That is, the failure or unavailability of this LRU would cause a mission to abort or render the aircraft "Not Mission Capable - Supply" (NMCS);

2. The management of this LRU should be representative of the major aspects of reparable asset management;

3. The LRU should be a high cost, high technology item since these items present the greatest challenge to policy-makers;

4. The LRU should be sufficiently representative of reparable assets in general so that only minor changes in the model structure and parameters would be required to adapt the model to any particular reparable asset.

In light of the foregoing criteria, the representative

LRU on which the development of the model would be based was chosen to be an avionics LRU. This LRU would be a "black box" item that could be replaced at the flight line and through this action return an aircraft to serviceable, fully mission capable (FMC) status.

Having selected an avionics LRU as the basis for the model, a further qualification was necessary. In recognition of the trend towards automated testing and repair-by-replacement, it was decided that this representative LRU should be supported by computerized test equipment (test stations), and should contain a number of replaceable subassemblies, which are themselves reparable items. These subassemblies are commonly referred to as Shop Replaceable Units (SRUs).

To summarize, the basis of the model developed by this research was chosen to be a mission critical LRU which is supported by computerized test equipment, and contains a number of shop replaceable units (SRUs). This choice of model basis was considered most appropriate for the development of a policy analysis model of the reparable asset system as it corresponds closely to the item management philosophy, and provides a model which is useful at all levels of policy-making. The selection of a time unit for the model is discussed next.

Selection of Model Unit of Time

Although the selection of a time unit for a model is arbitrary, the time unit employed should be realistic. That is, the time unit should not be so small that the measurement

of system parameters over such a short period is either impractical or will produce results of no significance to system managers. On the other hand, it should not be so long that significant behavior is masked by averaging over such a long period. For this research a period of one week was chosen as the model time unit since the majority of management decisions in the reparable asset system appeared to be based on weekly data.

Once the quantity basis of the model and the unit of time for the model had been decided, it was possible to commence the development of the model. The methodology employed in this development is discussed next.

Model Development Methodology

The theoretical and technological background to this research, the systems science paradigm and system dynamics modeling, provided the framework for the model development methodology. This methodology begins with the development of an initial conceptual model.

On the basis of personal experience, preliminary studies (1; 2; 3; 4) and interviews (16; 19), an initial conceptual model of the reparable asset system was developed. This model identified six major processes: demand generation, base level repair, quality effects, routine requisitions, depot repair, and depot resupply. These process sectors were then individually developed as the building blocks of the model (13:188-189). Causal-loop diagrams were developed for each sector, and these

were used to guide analysis and measurement of the elements and interrelationships between elements in each sector. Again, personal experience, interviews with logistics managers, and literature review were used to expand these sectors into dynamic flow diagrams and mathematical models of each sector. Once the major elements and interrelationships were described, the flow diagram and mathematical model were translated into equations in the DYNAMO simulation language. The sector simulations were then individually verified to insure that the computational sequence was correct and that the sector simulation behaved as intended. As each sector of the model was verified, it was combined with the sectors already completed and the combination was verified to insure correct behavior.

Once the entire model was assembled, it was validated through a series of unstructured interviews with logistics managers. These interviews used the consolidated model flow diagrams (Appendix B) as the basis for discussion. Included in the validation process was a review of system boundaries, a check for gross errors, a comparison of the structure of the model to the structure of the system, a check of parameter values, and finally a comparison of the model's behavior to that of the system. When the validity of the model was established, the model was evaluated for its usefulness as a policy analysis tool by conducting two representative experiments. Finally sensitivity analysis was carried out on the the model to determine the sensitivity of the model's behavior to changes in its parameters.

Summary

This chapter has provided the theoretical and technological framework of the research and the research approach which was developed from this framework. The next chapter documents the development of the proposed system dynamics policy analysis model of the Air Force reparable asset system.

CHAPTER 3

DEVELOPMENT OF THE MODEL

Introduction

The previous chapters have described the need and methodology for a dynamic policy analysis model of the Air Force reparable asset system. The goal of this research is to develop such a model in order to assist logistics managers in assessing the impact of policy decisions on the performance of the system. It has been established that the base level availability of serviceable assets is an extremely valuable indicator of system performance.

This chapter contains a discussion of the proposed model. As noted in Chapter 2, because of the complexity of the reparable asset system and the large number of factors involved, the model has been divided into seven major process sectors. These are:

1. Base LRU Demand Generation
2. Base LRU Repair Process
3. The Impact of Quality
4. Base LRU and SRU Repair Process
5. Base Routine Requisition Process
6. Depot Repair Process
7. Depot Resupply Process

The Base LRU Generation sector describes the factors that interact to create base-level demand for serviceable LRUs through the failure and replacement of unserviceable LRUs by serviceable components. The next two sectors describe the base level actions taken to repair LRUs and SRUs. Because of the complexity of this process, first a general description of the base level repair function is developed considering only LRUs. This is then elaborated upon by explicitly representing the flows and interactions of LRUs and SRUs in the base level repair process. The Base Routine Requisition Process sector describes the generation of routine resupply requisitions for reparable assets. The final two sectors describe the depot level actions taken to repair unserviceable LRUs returned from the base level, and to resupply base level stocks of LRUs from depot inventories of serviceable items. Priority (Mission Capability or MICAP) requisitioning, and asset condemnation and reacquisition are addressed in these sectors. In order to orient the reader to these sectors and the reparable asset system as a whole, Figure 3-1 presents a simplified block diagram of the simple reparable asset process.

Each process sector is developed in the following manner: first, each process is described and a structural model of the process, in the form of a causal-loop diagram, is proposed. Second, the structural model provides the basis for further development of a flow diagram of the process. Third, the flow diagram is then used to guide the writing of equations and functions in the DYNAMO simulation language.

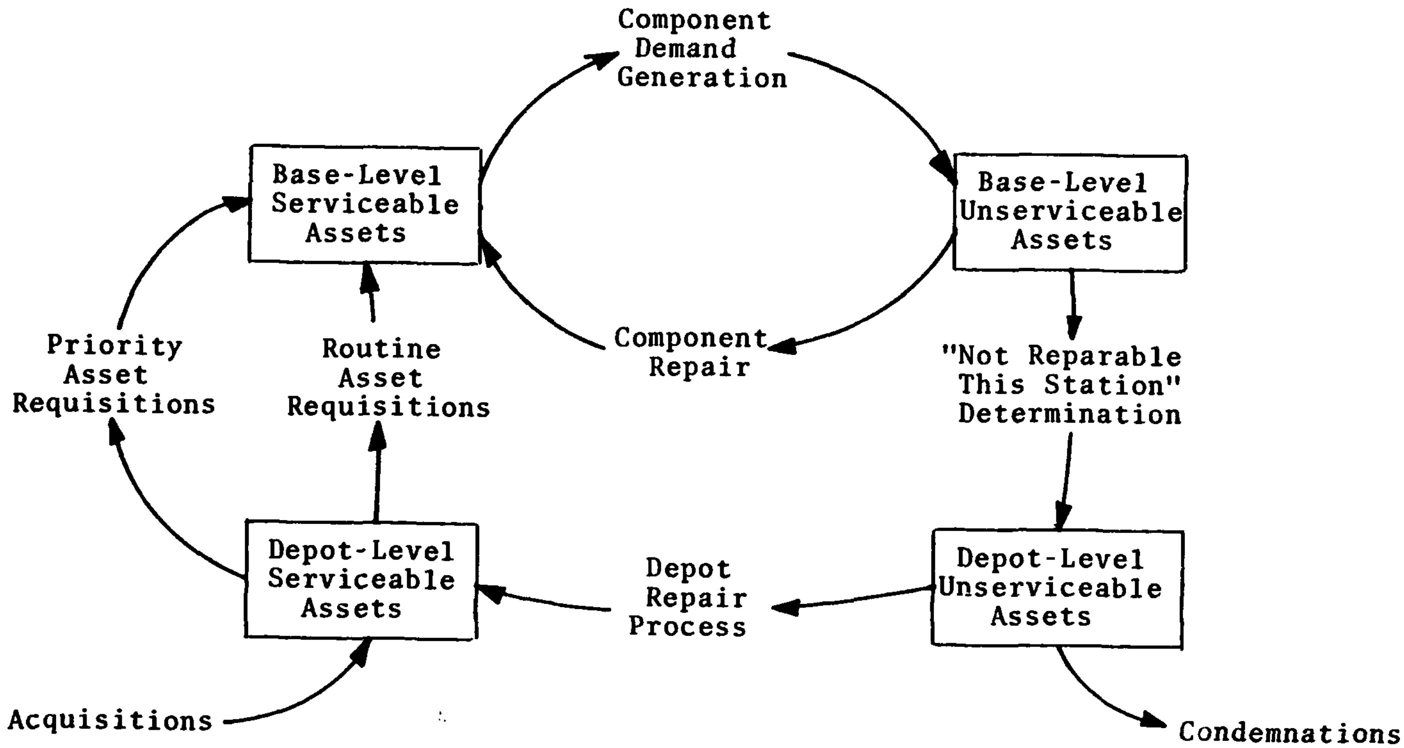


Figure 3-1

Air Force Reparable Asset System

The consolidated causal-loop diagrams of the model are presented in Appendix A. The consolidated flow charts of the model are contained in Appendix B. A consolidated and cross-referenced program listing of the DYNAMO equations and functions appears in Appendix C.

This chapter presents the final results of the model development work done for this thesis. As pointed out in Chapter 2, systems analysis and computer simulation are iterative processes. For the sake of clarity and brevity, the intermediate steps in model development have not been included here. The model as explained here is the final result of the application of the systems science paradigm explained in Chapter 2.

Base LRU Demand Generation

Process Description

As noted previously, the availability of serviceable assets at base level is a highly valuable indicator of the performance of the reparable asset system. It is, however, the demand for serviceable Line Replaceable Units (LRUs) that provides the driving force for the system. This sector describes the process whereby demands for serviceable LRUs are generated.

A distinction must be made between the failure of an LRU and a demand for a serviceable replacement LRU. In the course of its operation, an LRU may either malfunction or fail outright. During post-flight maintenance debriefings, this

incident would be reported, and a maintenance technician would be dispatched to correct the problem. If the problem can be diagnosed and corrected at the aircraft, repair is effected. If, however, the problem cannot be diagnosed and/or corrected at the aircraft, the technician would remove the failed LRU and replace it with a serviceable one demanded from base serviceable stock. Thus, the failure of an LRU may or may not create a demand for a serviceable replacement unit. The distinction is important since it suggests that the relevant factor is the Mean Time Between Demand (MTBD) for a given LRU, and not the component's Mean Time Between Failure (MTBF). Clearly, MTBF is a component of MTBD, but other factors also influence the MTBD and, consequently, the LRU demand rate. Among these factors would be the number of LRUs in operation (and, therefore, the number of serviceable LRUs at base level), the quality of maintenance work being performed, and the LRU utilization rate (i.e., the operational hours per time period). Implicit in the MTBD factor is the concept that this value is, in fact, the mean of the probability distribution of demands for a given LRU over time.

Of the factors mentioned only the LRU utilization rate may be considered to be an exogenous input to the reparable asset system. In theory the utilization rate can be set at any level, which the reparable asset system will then support or fail to support. In practice, while the utilization rate is usually set with the limitations of the reparable asset system as a consideration, interview results suggest

that this is clearly secondary to considerations of the mission scenario under study.

For the aircraft reparable asset system, the flying hour program imposed on the base by mission considerations determines the LRU utilization rate. Therefore, the flying hour program was chosen as the exogenous input for the model. This is consistent with current USAF planning, programming and budgeting practice.

Causal-Loop Diagram

On the basis of the foregoing a description of the base LRU demand generation process was developed (Figure 3-2). Starting with serviceable LRUs, the number of serviceable aircraft is directly related to the availability of serviceable LRUs. All other things being equal and given a constant flying hour program, as the number of serviceable aircraft increases, the flying hours required per aircraft will decrease in the aggregate. At the same time, increases in the flying hour program will increase the average number of flying hours per aircraft. As the flying hours per aircraft increase, the number of operational hours per LRU and the LRU failure rate will increase; consequently the LRU demand rate will increase. Increases in the LRU demand rate will decrease the inventory of serviceable LRUs.

Note that maintenance quality is also included as a factor in determining the LRU demand rate. At this point it is sufficient to note that maintenance quality is a separate

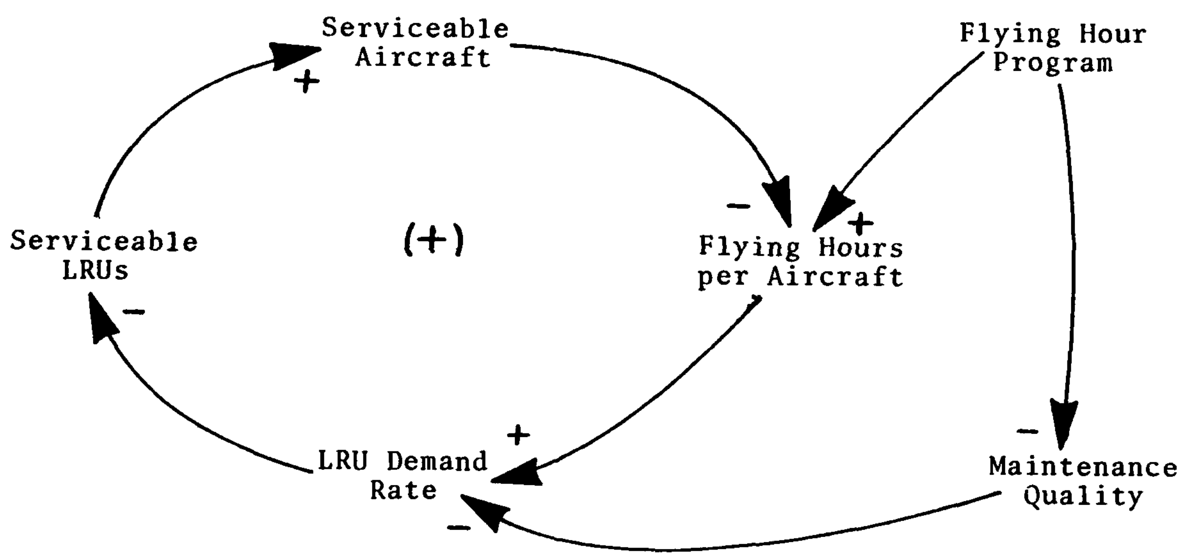


Figure 3-2

Causal-Loop Diagram for LRU Demand Rate Sector

and distinguishable factor in determining the LRU demand rate. That is, as the flying hour program increases, maintenance workload will increase and the quality of maintenace will suffer to some degree. Further, under the demand for more flying hours, there is a tendency for on-aircraft maintenance diagnosis and repair to be curtailed, since it may be quicker to simply remove and replace the suspect LRU with a known serviceable component in order to return the aircraft to service more rapidly. Full explanation of this process must await a description of the base LRU repair process, which will be taken up in the third sector.

Flow Diagram

The flow diagram for this sector (Figure 3-3; Table 3-1) was developed from the process description and causal-loop diagram above.

DYNAMO Equations

Using the flow diagram as a guide, the DYNAMO equations for this sector were developed in the following manner.

The LRU demand rate is a function of the rate of effort (ROE) of the base and the mean time between demand (MTBD) of the LRU under consideration. The two factors are derived by separate auxiliary variable structures and then combined to give the LRU demand rate (RDEM) in the equation:

```
R   RDEM.KL=ROE.K/MTBD.K
```

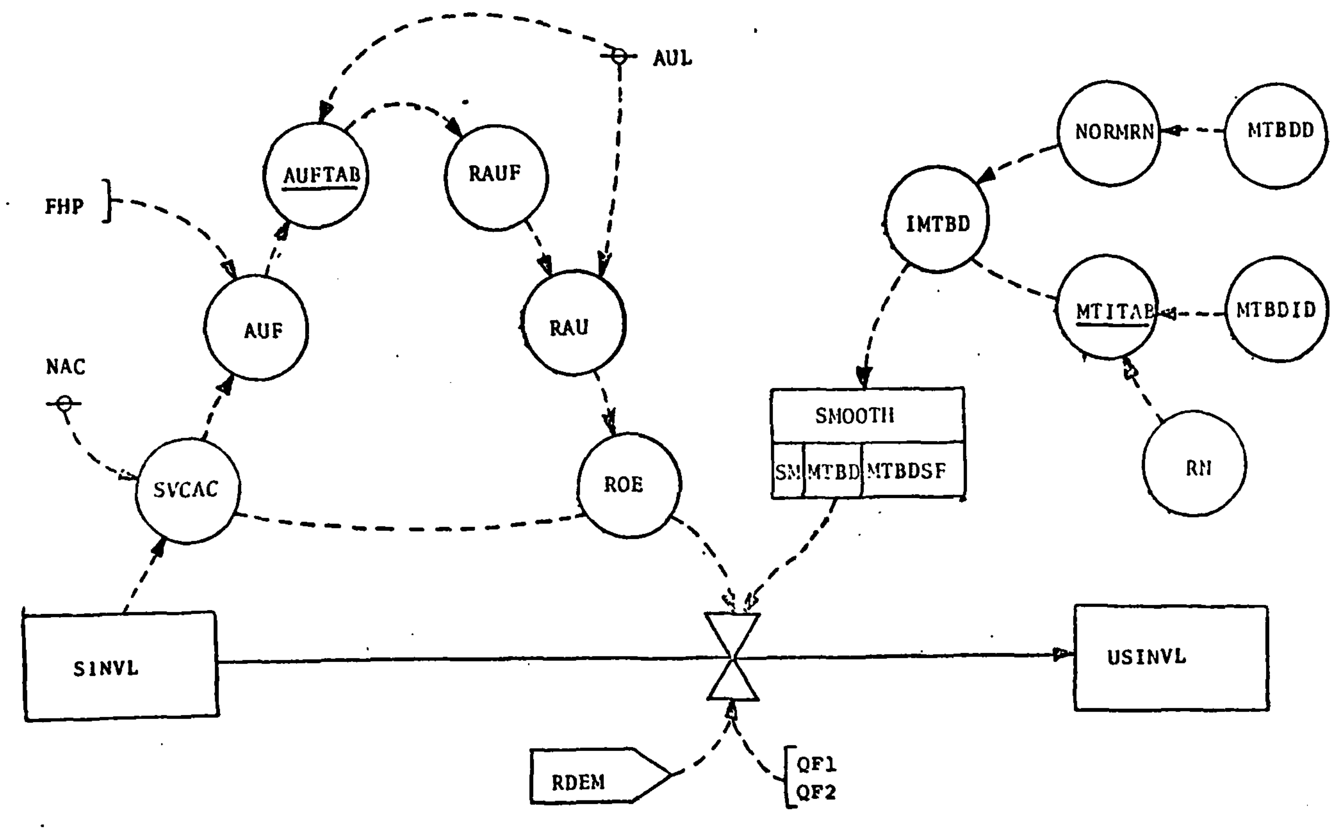


Figure 3-3

Flow Diagram for Demand Rate Generation Sector

TABLE 3-1

Variables Appearing in Figure 3-3

SCVAC	-	SERVICEABLE AIRCRAFT (UNITS)
SINVL	-	SERVICEABLE INVENTORY OF LRUS (LRUS)
NAC	-	NUMBER OF AIRCRAFT (UNITS
DAU	-	DESIRED AIRCRAFT UTILIZATION (FLY HR/WK/AIRCRAFT)
FHP	-	FLYING HOUR PROGRAM (FLY HR/WK)
RAUF	-	REALIZED AIRCRAFT UTILIZATION FACTOR
AUFTAB	-	AIRCRAFT UTILIZATION FACTOR TABLE
AUL	-	ABSOLUTE UTILIZATION LIMIT (FLY HR/AIRCRAFT/WK)
RAU	-	REALIZED AIRCRAFT UTILIZATION (FLY HR/AIRCRAFT/WK)
ROE	-	RATE OF EFFORT (FLY HR/WK)
MTBDD	-	MTBD DISTRIBUTION (FLY HR)
RN	-	RANDOM NUMBER
MTBDI	-	MTBD INTERVAL (WKS)
MTITAB	-	MEAN TIME INTERVAL TABLE
IMTBD	-	INSTANTANEOUS MTBD (FLY HR)
QF1	-	QUALITY FACTOR 1
QF2	-	QUALITY FACTOR 2
MTBDSF	-	MTBD SMOOTHING FACTOR (WKS)
RDEM	-	RATE OF DEMAND (LRUS/WK)

Rate of Effort Auxiliary Structure

The rate of effort is determined by the desired flying hour program (FHP) and the number of serviceable aircraft (SVCAC) available. As noted above, the flying hour program in this model is an exogenous input function and, therefore, can be specified as required in order to verify model functioning or to experiment with the model. The number of serviceable aircraft is determined by the availability of serviceable LRUs (SINVL) and the number of aircraft (NAC) assigned to the flying unit as follows:

```
A  SVCAC.K=MIN(SINVL.K,NAC)
C  NAC=72
```

For the initial model 72 was selected for NAC, corresponding to the 72 aircraft usually assigned to a tactical fighter wing. (See Chapter 2 for the discussion of this and other parameters.)

Having determined the number of serviceable aircraft available, this information can be used to derive the desired aircraft utilization (DAU). This factor represents the flying hour program on a per aircraft basis and is derived by:

```
A  AUF.K=FHP.K/SVCAC.K
```

In practice it is unlikely that the flying hour program will be spread equally over all available aircraft; and the desired aircraft utilization is not meant to be interpreted this way. A policy analysis model considers continuous aggregates of events as they would be perceived by policy-makers, rather

than the discrete events themselves. At this level of resolution it is not necessary (nor is it possible) to represent the specific aircraft on which an LRU demand occurs. The important point is that the determinant of the LRU demand rate is simply the total number of hours flown. However, using only the flying hour program in determining the LRU demand rate is unsatisfactory. There are practical restraints on whether or not the desired flying hour program (an exogenous factor) can be achieved by the resources represented in the model. It was important that the model address these constraints. In order to do this, a measure of aircraft utilization capability is required. The desired aircraft utilization is that measure. The desired aircraft utilization was selected because it can be described in purely practical, as opposed to abstract, terms, and because it can be readily measured.

Having described the desired aircraft utilization as a measure of the capability to meet the desired flying hour program, it was necessary to incorporate a means of limiting the actual flying hours realized due to constraints of the system. First, it was assumed that there is some limit to the number of flying hours per aircraft per week which can be achieved even under ideal conditions. The absolute utilization limit (AUL) represents this maximum limiting value in an ideal support environment and, therefore, should be determinable for any aircraft. It is perceived to be primarily a function of turnaround servicing, refueling, and rearming

requirements.

The desired aircraft utilization can be considered in relation to the absolute utilization limit. Over a wide range of system operations below the absolute utilization limit, the system will realize the desired aircraft utilization in response to flying hour program demands. However, maintenance management cannot respond to increased flying hour demands without limit. Due to such system constraints as manpower, physical resource constraints (other than LRUs or SRUs), and unscheduled maintenance requirements, it is unlikely that the weapon system will ever be able to achieve the theoretical absolute utilization limit. The impact of these constraints can be represented as a function of the ratio of the desired aircraft utilization (DAU) and the absolute utilization limit (AUL) (Figure 3-4).

The figure shows that over a fairly wide range of demands, the realized aircraft utilization factor (RAUF) equals the value of the ratio of DAU/AUL. As the value of the ratio approaches unity, however, the realized utilization factor begins to decrease, falling short of the value of DAU/AUL by an increasing amount because of the growing constraints on the system.

The upper limit on the realized aircraft utilization factor (0.85) was selected to suggest that the upper limit on maintenance management's ability to attain the absolute utilization limit is approximately 85 percent of that absolute limit. During validation of the model this point was discussed

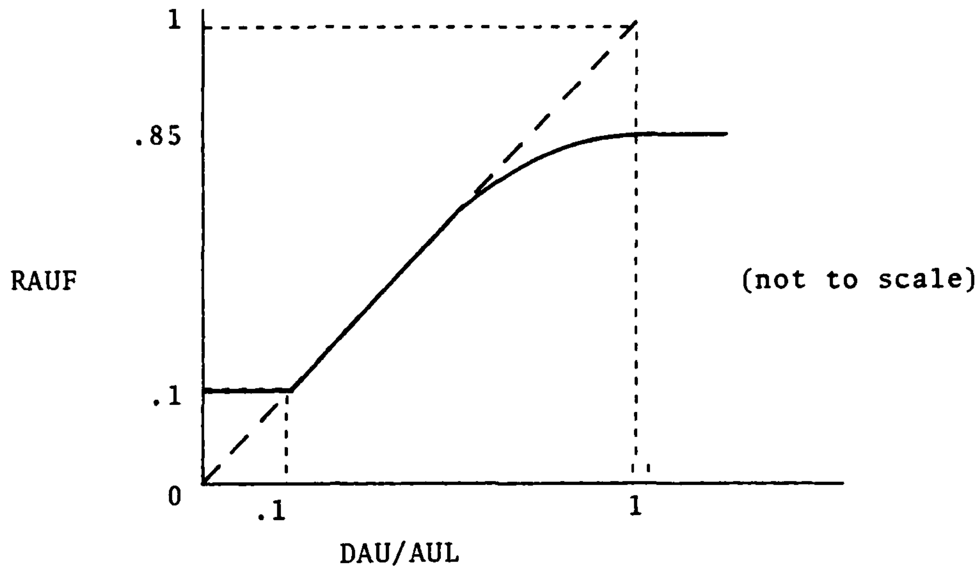


Figure 3-4

Derivation of Realized Aircraft
Utilization Factor

at length. While the absolute utilization limit is not well characterized, most persons consulted agreed that the concept as presented here is valid, and that the 85 percent limit is reasonable. Refer to Chapter 7 for a further discussion of this issue and relevant recommendations.

Note that Figure 3-4 depicts a lower limit on the realized aircraft utilization factor. This recognizes the fact that there is an extremely low minimum flying hour program that must be maintained by the system in order to justify the continued existence of the flying unit and to keep the assigned aircraft in an operationally ready state. In practice the system seldom, if ever, approaches this minimum

level of activity.

The foregoing discussion was implemented using one of the DYNAMO table functions, as follows:

```
A  RAUF.K=TABHL(DAUTAB,(DAU.K/AUL),0,1,0.1)
T  DAUTAB=.10/.10/.20/.30/.40/.50/.60/.70/.78/.83/.85
C  AUL=25
```

Using a value of 25 flying hours per aircraft per week for the absolute utilization limit, the current value of the ratio between the desired aircraft utilization (DAU) and AUL is computed and used to obtain the value of the realized aircraft utilization factor (RAUF) from the desired aircraft utilization table function, DAUTAB.

Since the resulting value of RAUF is dimensionless, the realized aircraft utilization obtained under a given set of conditions is computed by:

```
A RAU.K=RAUF.K*AUL
```

The rate of effort (ROE) is then obtained by:

```
A  ROE.K=FIFZE(0,(RAU.K*SVCAC.K),FHP.K)
```

Note that the actual value for the rate of effort is given by the second argument of the FIFZE macro. The FIFZE macro will return the value of the first argument if the third argument is zero; otherwise it returns the value of the second argument. Therefore, by using the FIFZE macro, the rate of effort may be set to zero if required. This overrides the DAUTAB table function which does not allow the realized

aircraft utilization factor and, therefore, the realized aircraft utilization to be zero. This will be useful in the model verification process, and allows the model to represent the short periods of zero rate of effort that may occur even when the flying unit is tasked with some definite flying hour program.

Mean Time Between Demand Auxiliary Structure

The mean time between demand (MTBD) in combination with the rate of effort (ROE) determines the LRU demand rate. Thus, for the purposes of this model the MTBD is defined as the number of flying hours between demands for a given LRU. This value is calculated by dividing the total flying hours for a given time period by the number of demands recorded in that period. This data would be readily obtainable from the existing maintenance management information data base, and represents the type of information used by maintenance managers in their decision processes.

There remains a question of whether the MTBD should be represented as a constant or a variable in the model. From a statistical standpoint, for any LRU there is an MTBD which is essentially constant over long periods of time. If this MTBD were used as a constant in the model, the demand rate derived would only vary as the rate of effort varied. In practice, however, the mean demand rate appears to fluctuate even though the rate of effort is constant. Therefore, a time varying representation of the MTBD should yield more

realistic model behavior. But how should MTBD vary?

In a continuous simulation model it is not realistic to randomly sample the MTBD distribution in every solution interval, since the real system would not experience such variations over such short time periods. A random, but gradually changing, MTBD fluctuation seems more realistic. Obtaining this type of random fluctuation is explained in the subsequent discussion.

An MTBD value would be selected from an MTBD sampling distribution obtainable by field observation. According to the central limit theorem, this distribution would be normal, and thus could be represented by a random normal variate selected from the given distribution (25:64-68, 187). In addition, the model time interval over which this MTBD might act could be randomly varied as well. This would provide a statistically valid, randomly varying MTBD which remains constant for random lengths of time. The output of such a computation, if plotted over time, would appear as an irregular square wave (Figure 3-5).

Although such an approach would be statistically valid, it would not be a realistic representation since the system would not be expected to experience large, instantaneous changes in MTBD. Rather, it would be expected that more gradual changes would be observed, as shown in Figure 3-6.

Following this logic, MTBD behavior as shown in Figure 3-6 was put into the model. This behavior is implemented in the following DYNAMO equations:

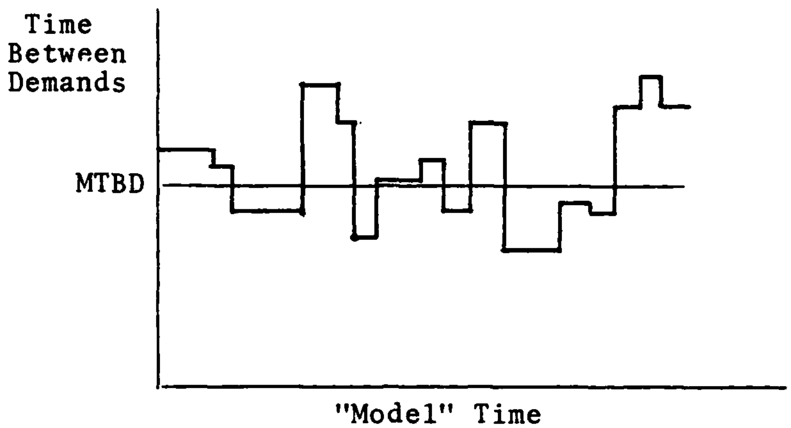


Figure 3-5

Fully Random Square Wave
MTBD Representation

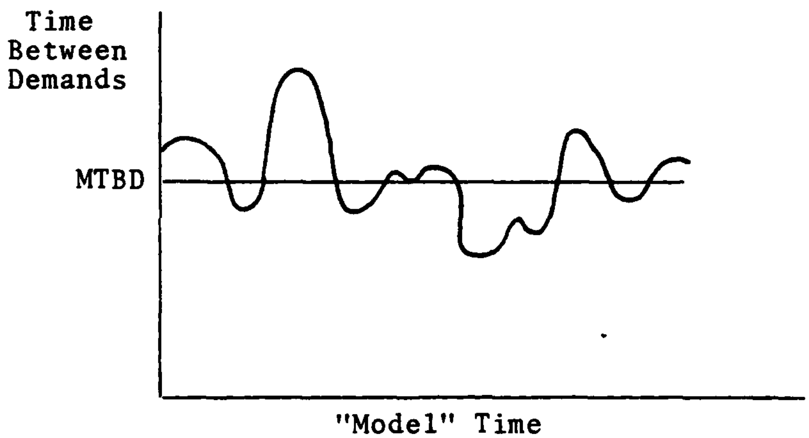


Figure 3-6

Fully Random Smoothed
MTBD Representation

```
A  MTBDD.K=NORMRN(250,20)
A  RN.K=NOISE()
A  MTBDI.K=TABHL(MTITAB,RN.K,-.5,.5,1)
T  MTITAB=4/12
A  IMTBD.K=SAMPLE(MTBDD.K,MTBDI.K,250)
A  MTBD.K=SMOOTH(IMTBD.K,MTBDSF)
C  MTBDSF=5
```

In these equations the MTBD sampling distribution (MTBDD) is established as a normal distribution with a mean of 250 hours and a standard deviation of 20 hours.

Once the MTBD is selected from this distribution, it will be held for a time interval of 4 to 12 weeks selected from a uniform probability distribution (MTITAB). The SAMPLE macro randomly selects the instantaneous value of MTBD (IMTBD) from the MTBD distribution, and holds it for the time interval randomly selected from the mean time interval table (MTITAB). The MTBD used to compute the rate of effort is derived from the SMOOTH macro which provides a gradual transition between the instantaneous MTBD (IMTBD) values obtained above. The value of the MTBD smoothing factor (MTBDSF), 5 weeks, was selected because it provided what appeared to be a realistic output during verification.

This concludes the discussion of the base LRU demand generation sector. This sector accepts an exogenous flying hour program input, converts this to a realistic rate of effort with a time-varying mean time between demand function. This produces a realistic demand rate input function for the

reparable asset processing system model. The complete DYNAMO statements for this sector are found in Appendix C, line numbers 1-1 to 1-16.

Base LRU Repair Process

Process Description

This sector considers the base level process through which unserviceable line replaceable units (LRUs) are repaired and returned to the serviceable inventory. As a result of flying operations, LRUs fail and are replaced with serviceable components, thus decreasing the base serviceable inventory and increasing the inventory of unserviceable LRUs awaiting assessment and repair by base maintenance. As the unserviceable inventory builds up, maintenance managers increase shop work rates in order to return unserviceable LRUs to the serviceable inventory more rapidly. At the same time, a certain percentage of the unserviceable LRUs will be beyond the repair capability of the base level shops; these will be declared Not Repairable This Station (NRTS) and returned to the appropriate depot technical repair center. As noted in the previous sector, under the pressure of increased work rates, the quality of maintenance will suffer to some degree and cause more failures of serviceable components which will, in turn, increase the LRU demand. The magnitude of this quality factor is a function of the persistance of the increased work rate pressures. Quality will be explicitly addressed in the next sector.

Causal-Loop Diagram

The relationships described above are depicted in the causal-loop diagram for this sector (Figure 3-7). This diagram illustrates that the LRU demand rate derived in the previous sector is the driving input to this sector. As the LRU demand rate increases, the number of serviceable LRUs decreases and the number of unserviceable LRUs increases. In response to the increase in unserviceable LRUs, the LRU repair rate increases, which leads to an increase in the number of serviceable LRUs and, therefore, a decrease in the number of unserviceable LRUs. Changes in the LRU repair rate also are affected based on the LRU demand rate as perceived by maintenance managers. Also, as the number of unserviceable LRUs increases, the NRTS rate (but not percentage) increases. As noted above, increases in the LRU repair rate tend to have a negative impact on maintenance quality which, in turn, causes the LRU demand rate to increase.

Flow Diagram

The process description and causal-loop diagram were used to develop the flow diagram for this sector (Figure 3-8 and Table 3-2). The diagram shows that the base LRU repair sector is comprised of three levels and three rates. The key rate in the sector is that at which unserviceable LRUs enter the repair process (RUSUR). This rate effectively determines how rapidly unserviceable LRUs will be assessed by the maintenance activity, and either disposed of through NRTS action

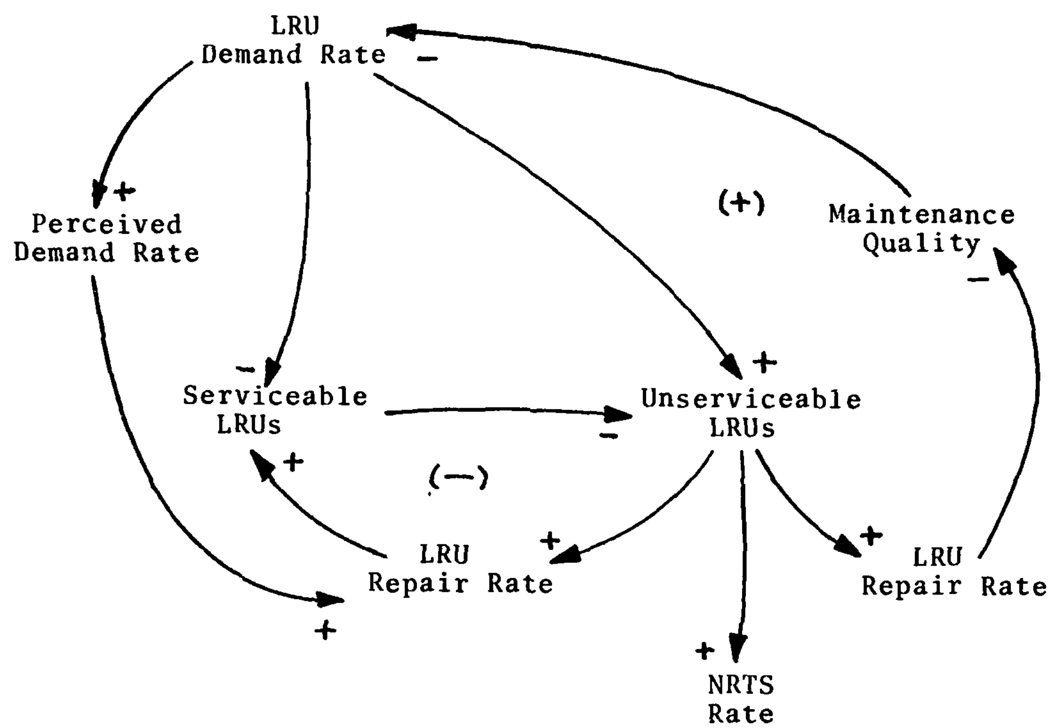
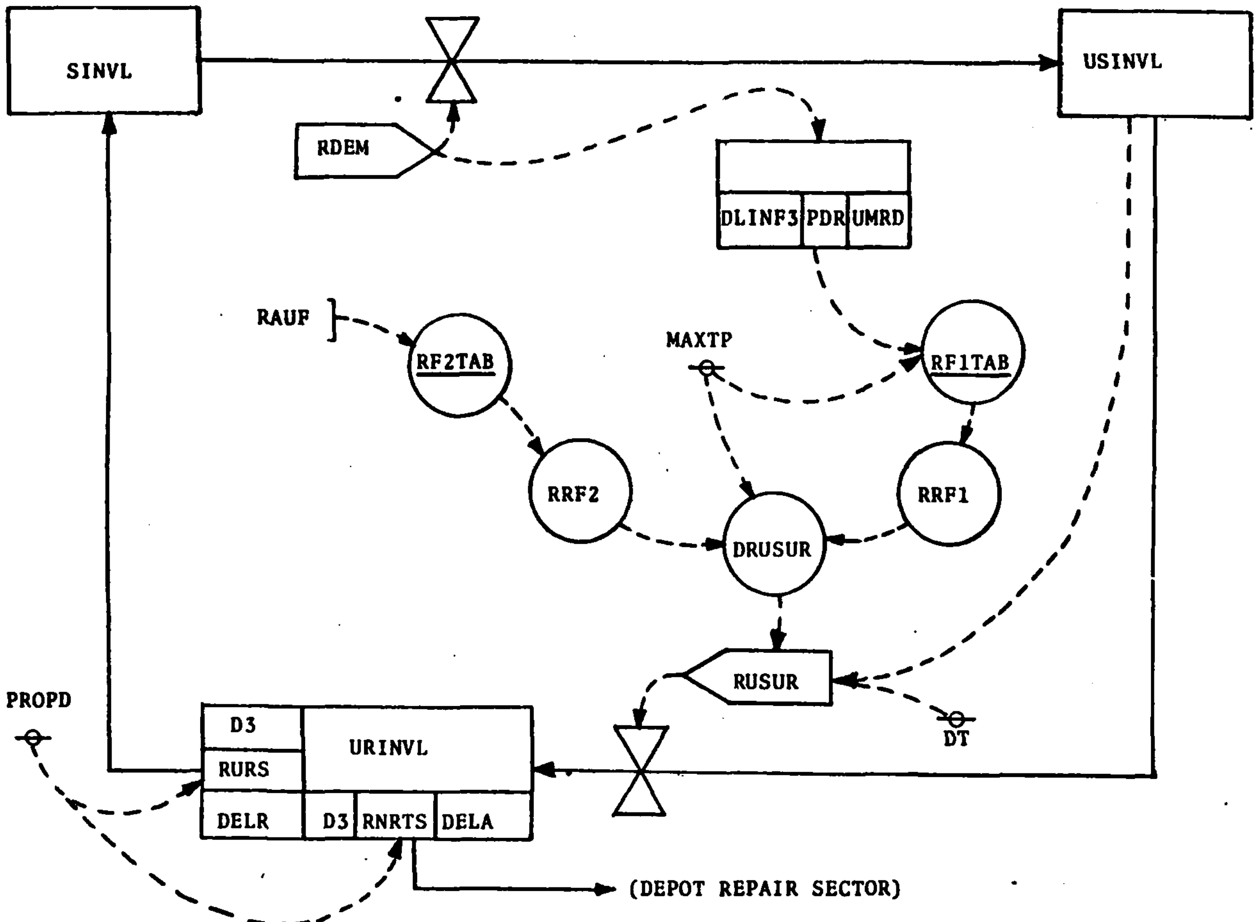


Figure 3-7

Causal-Loop Diagram for Base LRU
Repair Process



(DEPOT REPAIR SECTOR)

Figure 3-8

Flow Diagram for Base LRU Repair Process Sector

TABLE 3-2

Variables Appearing in Figure 3-8

SINVL	-	SERVICEABLE INVENTORY (LRUS)
RDEM	-	LRU DEMAND RATE (LRUS/WK)
USINVL	-	UNSERVICEABLE INVENTORY (LRUS)
PRR	-	PERCEIVED DEMAND RATE (LRUS/WK)
UMRD	-	UNIT MAINTENANCE RESPONSE DELAY (WKS)
RAUF	-	REALIZED AIRCRAFT UTILIZATION FACTOR
MAXTP	-	MAXIMUM THROUGHPUT (LRUS/WK)
RF1TAB	-	REPAIR RATE FACTOR 1 TABLE
RRF1	-	REPAIR RATE FACTOR 1
RF2TAB	-	REPAIR RATE FACTOR 2 TABLE
RRF2	-	REPAIR RATE FACTOR 2
DRUSUR	-	DESIRED RATE AT WHICH UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
RUSUR	-	RATE AT WHICH UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
URINVL	-	UNDER REPAIR INVENTORY (LRUS)
RNRTS	-	RATE AT WHICH LRUS ARE DECLARED NRTS (LRUS/WK)
DELA	-	DELAY FOR NRTS ASSESSMENT (WKS)
RURS	-	RATE UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)
DELR	-	LRU REPAIR DELAY (WKS)
PROPD	-	PROPORTION OF LRUS RETURNED TO DEPOT FOR SERVICING

or repaired and returned to serviceable condition.

As shown in the causal-loop diagram (Figure 3-7), there are two major influences on the LRU repair rate. The first is the perceived demand rate pressure. The second is LRU inventory level pressure. Because of the importance of these factors, they will be dealt with at some length.

One of the factors influencing how maintenance managers set their work rate is the perceived, or anticipated, demand rate for serviceable LRUs. A change in the real demand rate must be perceived by maintenance managers as significant before it affects the work rate. An apparently small or short-term change will not have a significant effect on the work rate. This reflects maintenance managers' reluctance to reprogram scarce resources such as manpower, equipment and spare parts from one task to another, until the change is warranted. Once the perceived change in the LRU demand rate becomes significant, managers will increase the work rate at an increasing rate until it begins to approach the perceived demand rate. At this point the rate of increase in work rate would decrease until the demand rate is balanced by the work rate.

There are two significant constraints on the ability to increase the rate at which unserviceables go under repair. The most obvious limitation is the level of unserviceable LRUs available for repair. The second constraint is the maximum throughput which the maintenance shop can achieve, given limitations on manpower, test equipment, and the like. This maximum throughput is a limitation imposed by the design of

the maintenance activity and could be measured by field observation. The relationship between the perceived demand rate (PDR), the maximum throughput, and the repair rate that managers establish as a result of those factors is presented in Figure 3-9.

Although it appears relatively simple, this figure incorporates the major behavioral characteristics of maintenance managers with regard to perceived demand pressure. The input to the repair rate factor one (RRF1) graph is the ratio of the perceived demand rate (PDR) to the maximum throughput rate of the workshop (MAXTP). This ratio reflects the pressure felt by maintenance managers as the perceived demand rate increases. Increasing values of the ratio PDR/MAXTP indicate growing pressure on maintenance managers to work harder to meet perceived demand rate.

The shape of the response function in Figure 3-9 represents the reluctance to increase the work rate until a significant level of pressure to do so is felt by maintenance managers. Once the managers are aware of this pressure, their reluctance is overcome and the work rate becomes more responsive to perceived demand rate changes until the limiting maximum throughput value is approached. Near this limit (as the ratio PDR/MAXTP approaches unity), it becomes more and more difficult to increase the work rate. At the limit, no amount of additional pressure will increase the work rate. Beyond this point, the perceived demand rate exceeds the maximum throughput and the backlog of unserviceable LRUs (USINVL)

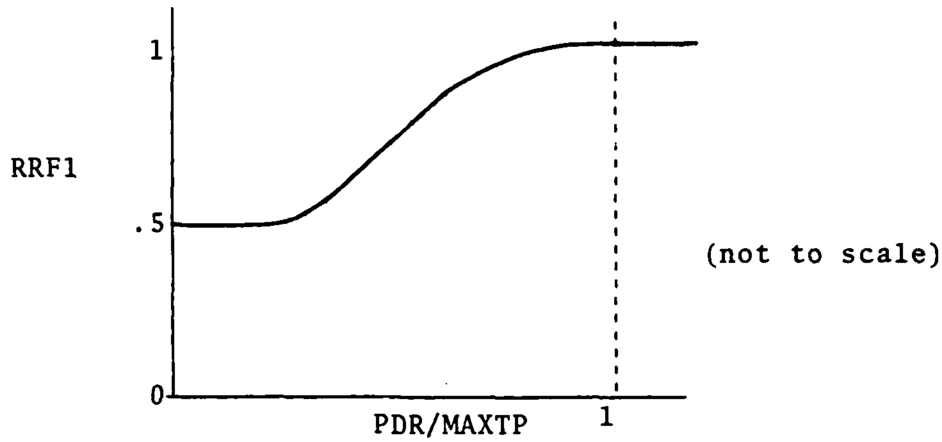


Figure 3-9

Derivation of Repair Rate Factor 1

accumulates.

Note that a lower limit on the work rate is also established in Figure 3-9. Thus, the work rate never drops to zero, even when the perceived demand rate is zero. In practice, even with the perceived demand rate equal to zero, the workshop would continue to operate at the same rate until the backlog in the unserviceable LRU inventory is reduced to zero. To determine this lower limit on the work rate, two situations must be considered.

The first is the possibility that there is no pressure at all to work at any specific rate. In this case workers in the maintenance shop will tend to work at some "natural" minimum rate. To work at a rate less than this rate would require more effort (be uncomfortably slow) than the natural

minimum rate. This minimum rate was established at one-half of the maximum throughput rate, thus the intercept of .5 on the vertical axis of Figure 3-9.

The second situation to consider is that in which the actual LRU demand rate is zero; therefore, there is no pressure from this source to maintain a high work rate. (Recall that this situation may occur only when the flying program rate of effort is zero.) In this case, unlike the first, management might be expected to maintain the pressure to keep the work rate at its current level for some time after the rate of demand drops to zero. In practice, this type of behavior occurs after short periods of high rate of effort due to sudden flying hour surges (operational readiness exercises or inspections). After these surges in rate of effort, there usually follows a period of minimal or zero rate ot effort. During this time maintenance managers must sustain the high work rate attained during the surge in order to reduce the number of unserviceable LRUs to what they perceive is an acceptable level.

Because of the persistance of the LRU repair rate implied by the lower limit in Figure 3-9, the influence of the unserviceable LRU inventory again must be considered. At low levels of unserviceable inventory the minimum work rate determined by the repair rate factor graph (Figure 3-9) cannot be supported. In practice, when these low levels of unserviceable inventory exist, managers will continue to set their work rate equal to at least the minimum level depicted

in Figure 3-9. When all backlog has been exhausted, the maintenance resources involved will be idle or diverted, temporarily, to other functions. The important point to note here is that while actual maintenance work, when performed, goes on at its natural rate, the effective rate over any given period is lower than this minimum rate. This situation must be addressed explicitly in the DYNAMO equations which follow.

Though perceived demand pressure accounts for much of the behavior of maintenance managers regarding desired work rates, there are other pressures which work to change the rate of LRU repair. These can be summed up as LRU inventory level pressures. These pressures grow as the serviceable LRU inventory declines to a point where there is a high probability of an aircraft being declared as Not Mission Capable - Supply (NMCS). As a result of this situation, there will be increasing pressure put to bear on the maintenance workshop to increase its work rate and, thereby, avoid a possible NMCS situation. This pressure is essentially independent of the perceived demand pressure, since in some circumstances the demand rate can be very low (when the rate of effort is low because of a shortage of serviceable aircraft); yet there will still be pressure in the system because the flying hour program is high. In this situation there would be considerable pressure to increase the serviceable LRU inventory and, consequently, the number of serviceable aircraft available to meet the flying hour program.

In order to derive an index for this pressure, recall

that in the discussion of demand rate generation it was pointed out that the realized aircraft utilization factor (RAUF) would begin to fall short of the desired aircraft utilization as the absolute utilization limit was approached. Specifically, it was noted that this limiting of desired aircraft utilization would begin at 70 percent of the absolute utilization limit. Thus, RAUF provides a measure of the inventory pressure on the base level system. Figure 3-10 shows this behavior in more detail.

In the figure, RRF2 is the percentage of the maximum throughput that maintenance managers would desire to set in response to the inventory level pressure indexed by RAUF. It was assumed that, again, the minimum natural work rate is 50 percent of the maximum throughput. Further, it was assumed that there would be little inventory pressure on the system up to about 50 percent of the RAUF at which NMCS actions are likely. After this point, as the inventory pressure increases, the maintenance workshop responds by setting higher and higher work rates until the RAUF approaches 0.70. As this occurs, the workshop approaches its maximum throughput and it becomes increasingly difficult to respond to the inventory level pressures.

In combination, the two pressures on maintenance will determine the rate at which unserviceable LRUs go under repair (RUSUR). Due to the independence of the two factors (RRF1 and RRF2), it was assumed that the greater pressure would predominate at any one moment. This will be specifically

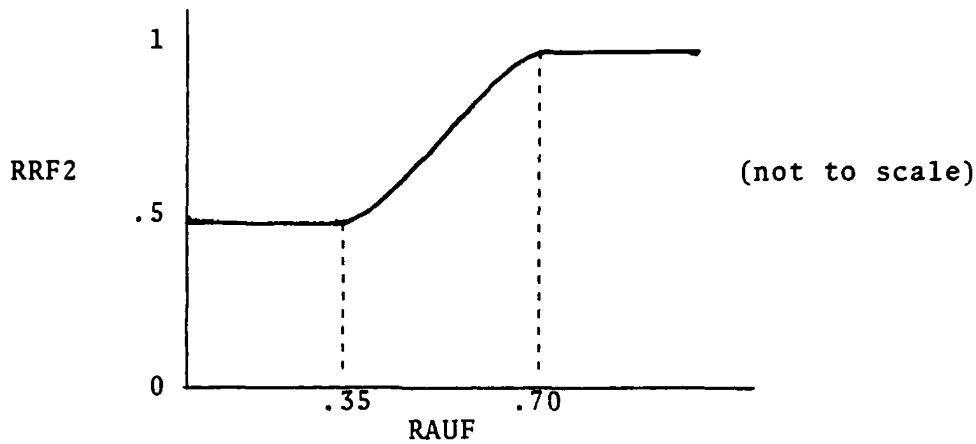


Figure 3-10

Derivation of Repair Rate Factor 2

represented in the DYNAMO equations that follow.

This structure does not specifically take into account the effects that shop replaceable units (SRUs) have on LRU repair. Though this is an important factor, the current structure assumes an unlimited supply of SRUs. The impact of SRU availability on LRU repair will be addressed in the next sector.

DYNAMO Equations

As previously noted, there are two factors influencing the rate at which unserviceables undergo repair: the perceived demand rate pressure and the inventory level pressure. The DYNAMO statement used to implement these factors in the model will be addressed in that order.

The maintenance managers' perceived demand rate (PDR) is a function of the actual LRU demand rate (RDEM) and may be

expected to lag behind the actual rate. Therefore, the decision process by which managers set their work rate has been represented by an auxiliary structure that links RDEM with the rate at which unserviceables undergo repair (RUSUR) through a third-order exponential information delay. This structure was used to obtain an approximation of the demand rate perceived by maintenance managers. This recognizes the fact that the manager's perceived demand rate would lag behind the actual rate under all circumstances except when the LRU demand rate is constant. The DYNAMO DLINF3 macro simulates the characteristics of this information lag:

```
A  PDR.K=DLINF3(RDEM.JK,UMRD)
C  UMRD=2
```

The unit maintenance response delay (UMRD) in the statement is the average perception delay experienced by maintenance managers, and reflects the time it takes for maintenance managers to become convinced of the significance of changes in the actual LRU demand rate.

The maximum throughput (MAXTP) of the maintenance shop is a design constant of the system:

```
C  MAXTP=2
```

For this model MAXTP was set to 2 LRUs per week through the following reasoning. The typical avionics LRU on which the model is based would have to compete for servicing time on automatic test equipment stations with other similar LRUs. The average test station time required by this type of LRU is

on the order of four to six hours and, given that the test station supports a number of LRUs, a maximum throughput limit of two per week seemed reasonable.

The ratio of the perceived demand rate (PDR) to the maximum throughput (MAXTP) is used to represent the pressure that maintenance managers feel to increase their work rate. The behavior of managers with respect to this pressure was shown in Figure 3-9, and was implemented in the model using the TABHL macro:

```
A  RRF1.K=TABHL(RF1TAB,PDR.K/MAXTP,0,1,0.1)
T  RF1TAB=.5/.5/.53/.58/.65/.73/.82/.91/.97/.98/1.0
```

The resulting value of the repair rate factor (RRF1) is dimensionless. It represents the actual percentage of the maximum throughput capability that maintenance managers desire to use, given the demand pressure they feel.

The other major pressure in the base level LRU repair process is the inventory level pressure. The behavior of managers with respect to this pressure was shown in Figure 3-10, and was implemented in the model using the TABHL macro:

```
A  RRF2.K=TABHL(RF2TAB,RAUF.K,0,.7,.1)
R  RF2TAB=.5/.5/.51/.54/.66/.88/.99/1.0
```

The resulting value of the repair rate factor (RRF2) is also dimensionless. It represents the actual percentage of the maximum throughput capability that the maintenance managers desire to use, given the inventory level pressure they feel.

As noted before, the actual desired rate of

unserviceables undergoing repair (DRUSUR) will be the larger of the two rates specified by either RRF1 or RRF2. Thus,

```
A DRUSUR.K=MAX(RRF1.K*MAXTP,RRF2.K*MAXTP)
```

The other major factor in determining the rate at which unserviceable LRUs undergo repair is the level of the unserviceable LRU backlog (USINVL). Very low levels of USINVL limit the rate at which unserviceable LRUs undergo repair. At low levels of USINVL, the work rate (DRUSUR) determined by either repair rate factor may exceed the available backlog. The DYNAMO statements for the rate at which unserviceable LRUs undergo repair (RUSUR) must allow for this constraint, or a negative USINVL value will result. To avoid this, the statement sets RUSUR to the value which will extract, over the next solution interval (DT), only the amount in USINVL at the end of the previous solution interval. In practice, this represents the situation in which the minimum work rate may be two LRUs per week, but there is only one LRU which requires repair in a given week. This LRU would be repaired at the minimum two per week rate. When the job is complete, the remaining time will be idle; the effective work rate would be one per week. The model implements this by computing this backlog-limited rate, and taking the full week to produce one serviceable LRU. Although this is not the same as repairing one LRU in half a week, the overall effect on the rate at which serviceable LRUs become available to the serviceable inventory (SINVL) is the same. The equation to determine RUSUR is:

R RUSUR.KL=FIFGE(USINVL.K/DR,DRUSUR.K,

DRUSUR,K,USINVL,K/DT)

The FIFGE macro returns the value of the first argument if the third argument is greater than or equal to the fourth argument; otherwise it returns the value of the second argument. Therefore, when the desired value of RUSUR (DRUSUR) determined from either repair rate factor table is greater than the rate which would reduce USINVL to zero over the next solution interval (i.e., USINVL.K/DT), the FIFGE macro sets RUSUR to the lower value.

The assessment and repair process is represented as two third-order delays. One (RNRTS) represents the assessment of LRUs which are beyond the repair capabilities of the base maintenance shop and, therefore, are declared Not Reparable This Station (NRTS). The other delay (RURS) represents the assessment and repair of LRUs at base level. The length of these delays and the proportion of NRTS LRUs are consistant with the general class of avionics LRUs. The DYNAMO statements are:

R RNRTS.KL=DELAY3(PROPD*RUSUR.JK,DELA)

R RURS.KL=DELAY3((1-PROPD)*RUSUR.JK,DELR)

C PROPD=0.2

C DELA=0.3

C DELR=1.2

The serviceable inventory level (SINVL), the unserviceable inventory level (USINVL), and the level of inventory

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under repair (URINVL) can all be determined by computing the net effect of the rates which act on them:

```
L  SINVL.K=SINVL.J+DT*(RURS.JK-RDEM .JK)
L USINVL.K=USINVL.J+DT*(RDEM .JK-RUSUR.JK)
L  URINVL.K=URINVL.J+DT*(RUSUR.JK-RURS.JK-RNRTS.JK)
```

In summary, this sector represents the processing of unserviceable LRUs at base level. The key factor in this sector is the rate at which unserviceable LRUs enter the repair process. The determination of this rate is achieved with an auxiliary structure which incorporates two table functions to represent the effects of physical and technological constraints on managerial decision-making. Table 3-3 lists all of the DYNAMO equations for this sector. The current representation, though adequate in most details, still assumes an unlimited supply of shop replaceable units (SRUs). A more satisfactory representation of the base level LRU repair process must await development of the model sector concerning the SRU repair process, which occurs later in this chapter. At that time the LRU repair sector equations will be augmented to explicitly include the impact of SRUs on the LRU repair process.

Quality Effects Sector

Process Descriptions

The quality of maintenance work at both the flight line and maintenance workshop levels is a matter of continuing concern to policy-makers. Inadequate maintenance at the flight

TABLE 3-3

DYNAMO Equations for Base LRU Repair Process Sector

```
L   USINVL.K=USINVL.J+DT*(RDEM.JK-RUSUR.JK-DTDR.JK)
N   USINVL=0
A   PDR.K=DLINF3(RDEM.JK,UMRD)
C   UMRD=2
A   RRF1.K=TABHL(RF1TAB,(PDR.K/MAXTP),0,1,.1)
T   RF1TAB=.5/.5/.53/.58/.65/.73/.82/.91/.97/.98/1.0
A   RRF2.K=TABHL(RF2TAB,RAUF.K,0,.7,.1)
T   RF2TAB=.5/.5/.5/.52/.66/.88/.99/1.0
A   DRUSUR.K=MAX(RRF1.K*MAXTP,RRF2.K*MAXTP)
R   RUSUR.KL=FIFGE(USINVL.K/DT,DURSUR.K,DRUSUR.K,USINVL.K/DT)
C   MAXTP=2
L   URINVL.K=URINVL.J+DT*(RUSUR.JK-RNRTS.JK-RURS.JK)
N   URINVL=0
R   RNRTS.KL=DELAY3(PROPD*RUSUR.JK,DELA)
C   DELA=0.3
C   PROPD=0.2
R   RURS.KL=DELAY3((1-PROPD)*RUSUR.JK,DELR)
C   DELR=1.2
L   SINVL.K=SINVL.J+DT*(RURS.JK+RARFD.JK+RAPFD.JK_RDEM.JK)
N   SINVL=BLRU
C   BLRU=80
```

line can severely reduce weapon system reliability and availability and could conceivably result in the loss of an aircraft. Poor quality control in the maintenance workshop can reduce LRU reliability. Such reduced LRU reliability can increase LRU failure rates and, consequently, LRU demand rates. As has been shown in the previous sectors, increased LRU demand rates drive the reparable assets system harder and harder, while reducing the availability of serviceable LRUs.

A wide variety of technological as well as psychological factors appear to influence the quality of maintenance. In terms of system behavior these factors can be grouped into two major categories: the impact that changes in the flying hour program have on flight-line maintenance, and the impact that increased shop work rates have on the quality of output. The nature of these influences is shown in Figure 3-11.

Causal-Loop Diagram

Figure 3-11 shows the influence of the two maintenance quality factors in combination with the LRU demand generation process sector and base level LRU repair process sector. With the addition of the maintenance quality factor, increases in the flying hour program act two ways to increase the LRU demand rate: first, by increasing the flying hours per aircraft as developed in the demand generation sector; second, by decreasing the quality of maintenance. This decrease in the quality of maintenance due to increases in the flying hour program relates to the observation that with the demand for

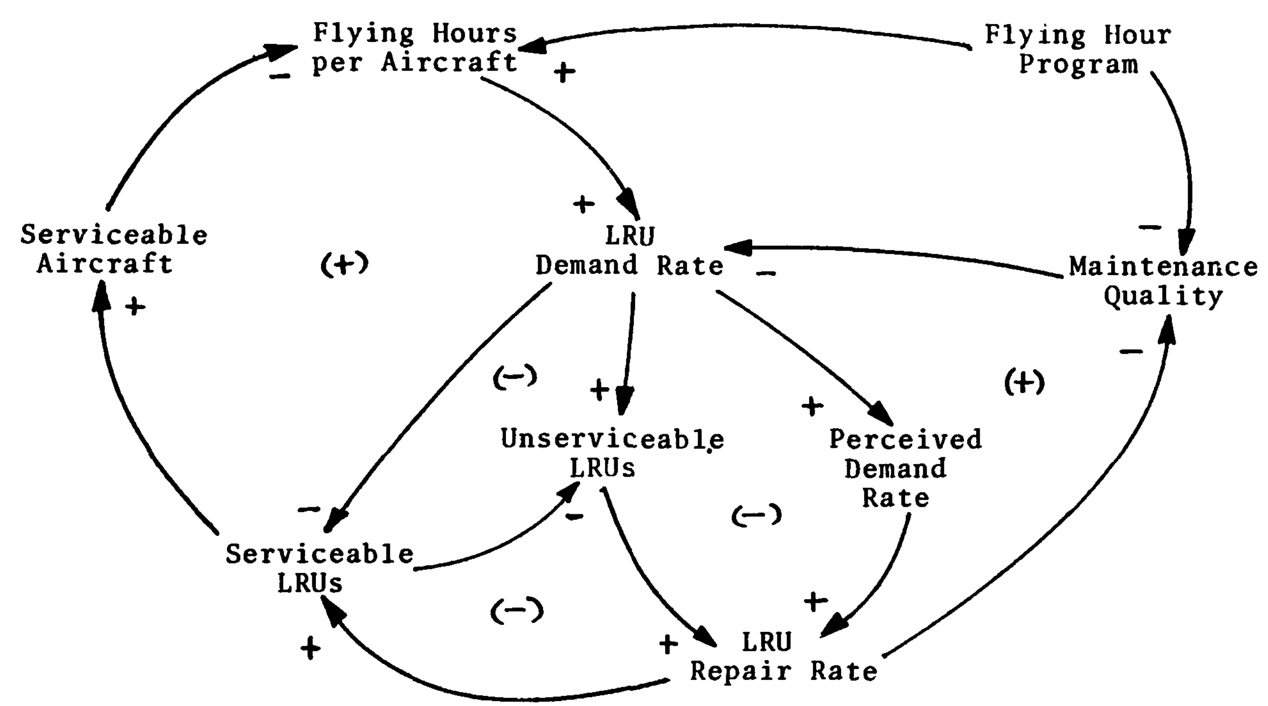

Figure 3-11

Causal-Loop Diagram for Quality Effects Sector

more flying hours there is a tendency to curtail on-aircraft maintenance diagnosis and repair. Maintenance managers often find it quicker to simply remove and replace a suspect LRU with a known serviceable component in order to return the aircraft to service more rapidly. This "on spec" changing of LRUs can have a significant impact on LRU demand rates.

Increases in the LRU repair rate also tend to decrease the quality of maintenance performed in the repair shops. As the pressure to increase the LRU repair rate grows, managers and technicians tend to spend less time on each maintenance task, thereby increasing the likelihood of errors. At the highest levels of pressure, quality control procedures may even be curtailed in order to return the LRU to serviceable stock rapidly. This decreased LRU maintenance quality acts to increase the LRU demand rate since the lower quality components tend to malfunction or fail more frequently. In this situation the net effect of maintenance quality is to amplify changes in the LRU demand rate.

Flow Diagram

The flow diagram incorporating the two factors of maintenance quality is shown in Figure 3-12 and Table 3-4. Recall that the model flow diagram (and the DYNAMO equations written to implement it) does not necessarily represent a given specific influence of quality on the system. The goal is, rather, to develop a means of representing the causal relationships observed and provide a vehicle for investigating the

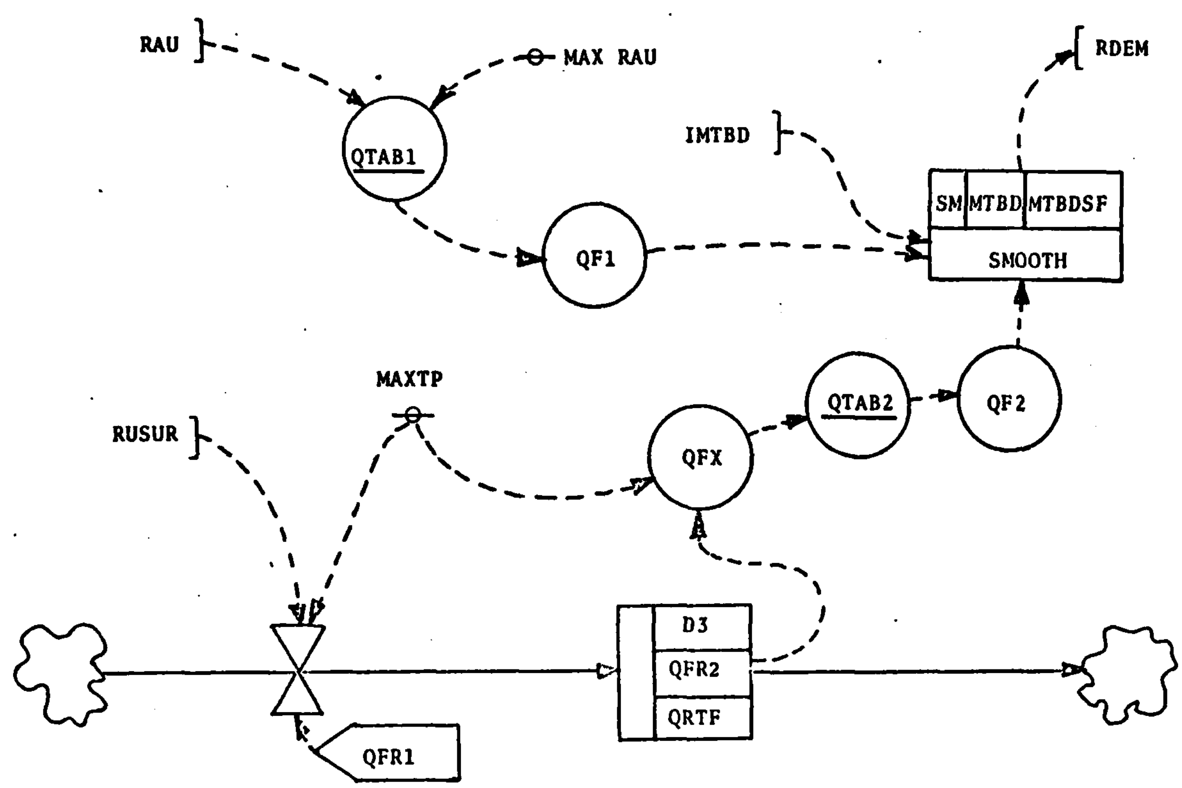

Figure 3-12

Flow Diagram for Quality Effects Sector

TABLE 3-4

Variables Appearing in Figure 3-12

QF1 -	QUALITY FACTOR 1
RAU -	REALIZED AIRCRAFT UTILIZATION (FLY HR/AIRCRAFT/WK)
QTAB1 -	QUALITY FACTOR TABLE 1
QFR1 -	QUALITY FACTOR RATE 1
RUSUR -	RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
MAXTP -	MAXIMUM THROUGHPUT (LRUS/WK)
QFR2 -	QUALITY FACTOR RATE 2
QRTF -	QUALITY RATE TIME FACTOR (WEEKS)
QFX -	QUALITY FACTOR INDEX
QF2 -	QUALITY FACTOR 2
QTAB2 -	QUALITY FACTOR TABLE 2

influence of quality on the system. If a reasonable representation of the causality can be obtained, experimentation with that model will show how sensitive the system is to quality. If quality proves to be significant, then further elaboration of the quality sector would be warranted.

In developing the flow diagram, it was assumed that the two influences of quality would act to decrease the mean time between demand (MTBD) developed in the demand rate generation sector; consequently, the LRU demand rate would increase. Two quality factors were developed to represent the two influences on maintenance quality. The first quality factor (QF1) represents the impact of changes in the flying hour program. The second quality factor (QF2) represents the impact of changes in the LRU repair rate.

The impact of the flying hour program on maintenance quality is related to the pressure the program places on the capacity of the weapon system under consideration. Recall that in the LRU demand rate sector the realized aircraft utilization (RAU) was developed as a function of the desired aircraft utilization and the absolute utilization limit of 25 flying hours per aircraft per week. In addition, the maximum value of realized aircraft utilization was defined as 85 percent of the absolute utilization limit, or 21.25 flying hours per aircraft per week. The ratio of the realized aircraft utilization to this maximum realizable aircraft utilization was then taken to represent the pressure that the current flying hour program is exerting on flight-line maintenance. This is reasonable

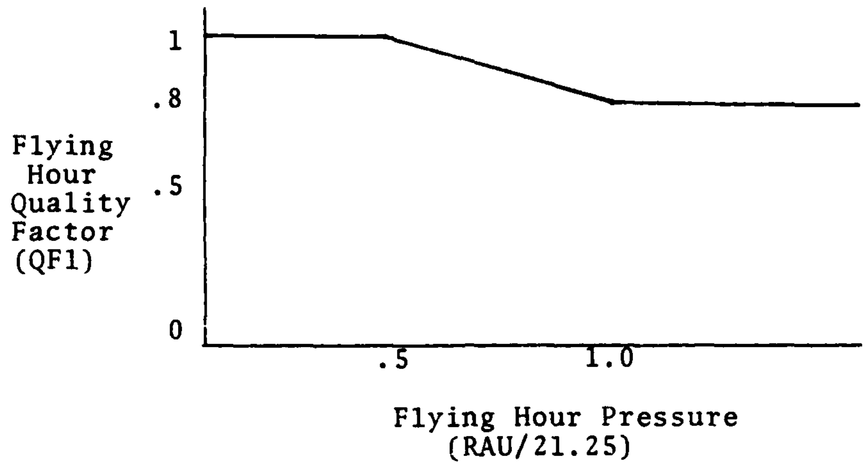

Figure 3-13

Impact of Flying Hour Pressure on Maintenance Quality

since the maximum realizable aircraft utilization recognizes the limitations of flight-line maintenance in generating the desired number of flying hours. As the realized aircraft utilization value approaches its maximum (as the ratio RAU/21.25 approaches unity), the pressure on maintenance quality increases and, at some point, that quality will begin to decrease.

The nature of this quality decrease is depicted in Figure 3-13. Note that until the realized aircraft utilization reaches one-half of its maximum value, there is no pressure on maintenance quality from the flying hour program. This is analogous to the linear region in Figure 3-9, where maintenance managers are still not particularly pressured to generate usable aircraft in response to the flying hour program. As the realized

aircraft utilization exceeds one-half of its maximum value, though, the pressure of the flying hour program begins to influence maintenance quality. Again, this is analogous to approaching and entering the non-linear upper region of Figure 3-9. Here maintenance managers are increasingly unable to meet the demands of the flying hour program as the constraints on the system become more and more profound.

This impact of flying hour pressure is not unlimited. At some point, maintenance managers will exert sufficient pressure to counteract the decrease in quality. Even under maximum flying hour pressure, it was assumed that there will only be a 20 percent loss of maintenance quality.

The impact of changes in the LRU repair rate is reflected in a conservative structure that represents the addition of lower reliability LRUs into the inventory of LRUs at the base level. This flow of components begins when the rate at which unserviceable LRUs go under repair reaches its maximum throughput value (MAXTP) of 2 units per week. Recall that at this point the unserviceable backlog will begin to build up if the LRU demand rate is greater than or equal to MAXTP. The effect of this build-up of unserviceables is to increase the pressure maintenance managers feel as they strive to keep that backlog at or below an acceptable level. It is during these periods of increased pressure that the lower quality shop maintenance described above will occur. Thus, during periods of maximum effort, there will be a leakage of lower reliability LRUs into the base inventory.

Once lower reliability LRUs have penetrated the base inventory, they remain until they again malfunction and are replaced. Stopping the pressure for high LRU repair rates prevents further penetration, but does not remove the lower reliability LRUs already in the inventory. The lower reliability LRUs which enter the inventory during periods of maximum maintenance shop output have their effect by lowering the MTBD of the LRU involved. However, this effect is not immediate. Rather, it is a time-dependent phenomena where the impact of lower maintenance quality is not very noticeable after short surges, but will become more and more obvious as the surges of maintenance effort become longer and longer. Further, because of the persistance of the lower reliability LRUs in the base inventory, their impact on the MTBD decays slowly over time. This decay is a function both of the degree of penetration of lower reliability LRUs into the inventory and of how long these LRUs persist in the inventory.

The process by which lower reliability LRUs penetrate, persist in, and decay from the inventory is represented in the flow diagram by a third-order exponential delay. The delay constant is the quality rate time factor (QRTF). This is equivalent to the average length of time it takes for lower reliability LRUs to have their effect on MTBD during surges of maximum maintenance activity. Conversely, QRTF is the average length of time it takes for the effect of lower reliability LRUs to lose their effect on MTBD after the maintenance workshop returns to less-than-maximum effort. The value of

the quality rate time factor was established as 10 weeks, based on the characteristics of the third-order exponential delay and the observation that at maximum throughput it would take approximately 40 weeks for two-thirds of the LRUs available to the base to pass through the workshop. It was assumed that the effect of low reliability LRUs would be at its maximum when two-thirds of the inventory was in the low reliability state.

Because of the conservative nature of the system, the quality factor effect (QFX) of changes in the LRU demand rate can be measured in terms of the ratio of the time-delayed effects of changes in the LRU demand (QFR2) to the maximum throughput of the system (MAXTP). As this ratio (QFR2/MAXTP) increases, the decrease in the LRU quality factor (QF2) also increases. The behavior of the system with respect to these changes is represented in Figure 3-14. Note that once the lower quality LRUs penetrate the base inventory, LRU quality (QF2) begins to influence the MTBD. This impact is limited, however, to a maximum of 10 percent. The limitation primarily reflects the fact that because of the highly automated nature of the avionics LRU repair process, there is a practical limit on the loss of reliability which will occur even under the pressure of increased LRU repair rates.

DYNAMO Equations

The DYNAMO equations for this sector follow in a straightforward manner from the flow diagram (Figure 3-10),

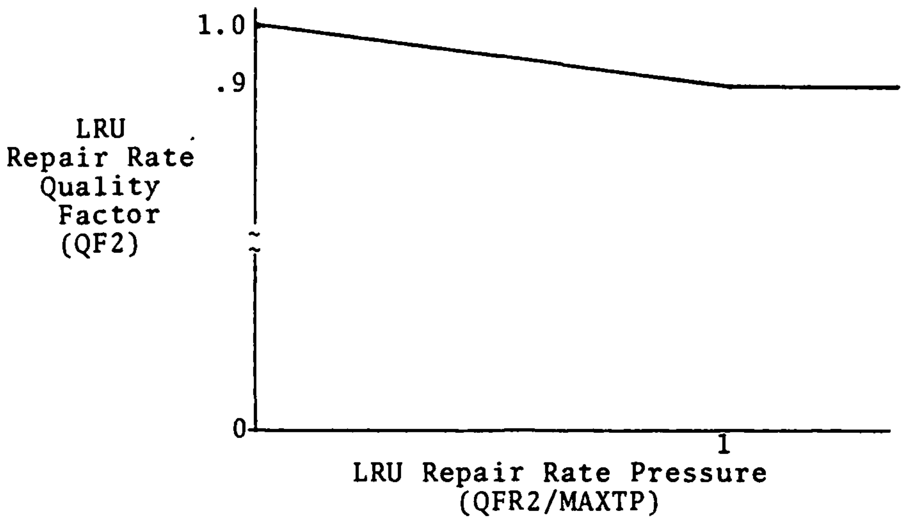

Figure 3-14

Impact of LRU Repair Rate on Maintenance Quality

and are found in Appendix C, line numbers 2-1 to 2-10. The impact of flying hour pressure represented in Figure 3-13 was converted to a TABHL function (QTAB1) from which the value of flying hour quality factor (QF1) is returned. The conservative structure representing the penetration and persistance of lower quality LRUs is controlled with a FIFZE function and mediated through a third-order exponential delay. The impact of LRU repair rate pressure represented in Figure 3-14 was converted to a TABHL function (QTAB2) from which the value of the LRU repair rate quality factor (QF2) is returned. The two quality factors are combined with the output of the MTBD auxiliary structure to derive the actual MTBD used in the model:

```
A  MTBD.K=QF1.K*QF2.K*(SMOOTH(IMTBD.K,MTBSF))
```

In summary, the quality impact sector derives the impact an MTBD of two distinct quality processes. The first process reflects the impact of changes in the flying hour program on the quality of on-aircraft maintenance. This process acts in an instantaneous manner to increase the LRU demand rate, reflecting the observation that, under the pressure of an increased flying hour program, maintenance managers tend to curtail on-aircraft maintenance activities and adopt a remove and replace philosophy. The second quality process reflects the persistant nature of changes in the LRU repair rate on the quality of the components repaired. This process acts in a time-delayed manner which recognizes the impact of a build-up of lower reliability LRUs on the mean time between demand. Acting together, these two processes tend to amplify changes in the LRU demand rate.

Base Level LRU and SRU Repair Process Sector

The representation of base-level LRU repair presented in the LRU repair process sector did not specifically address the interaction of shop replaceable units (SRUs) with the LRU repair process. This presentation is adequate only if one or more of the following conditions are met:

1. the model is used to investigate reparable asset processing for LRUs that contain no SRUs,

2. the model user is prepared to assume that the availability of serviceable SRUs will not significantly limit

the LRU repair rate, and

3. the model user considers it adequate to incorporate the effect of SRU availability in the specification of the delay for the LRU repair process discussed above.

If none of the above apply, the model must include SRU processing and its interaction with the processing of LRUs. This sector describes how the interaction between LRUs and SRUs was incorporated into the model.

Process Description

In order to incorporate SRUs into the LRU repair process model developed in the last sector, the process was divided into two steps. First, the faulty SRUs are identified and removed from the LRU. Second, replacement SRUs are installed and the LRU is returned to a serviceable condition. In the second step of the process, any calibration or other repair action not requiring the replacement of SRUs is also carried out. Between these two steps the LRUs are held in an under-repair inventory awaiting the availability of SRUs. It should be noted that while the model represents these processes sequentially, in practice they can occur concurrently if the required SRUs are available at the time of diagnosis.

Causal-Loop Diagram

Figure 3-15 is the causal-loop diagram for this sector. It clearly shows the parallel lines of causality that combine to determine the interaction of SRUs in the LRU repair process. Increases in the volume of unserviceable LRUs increase

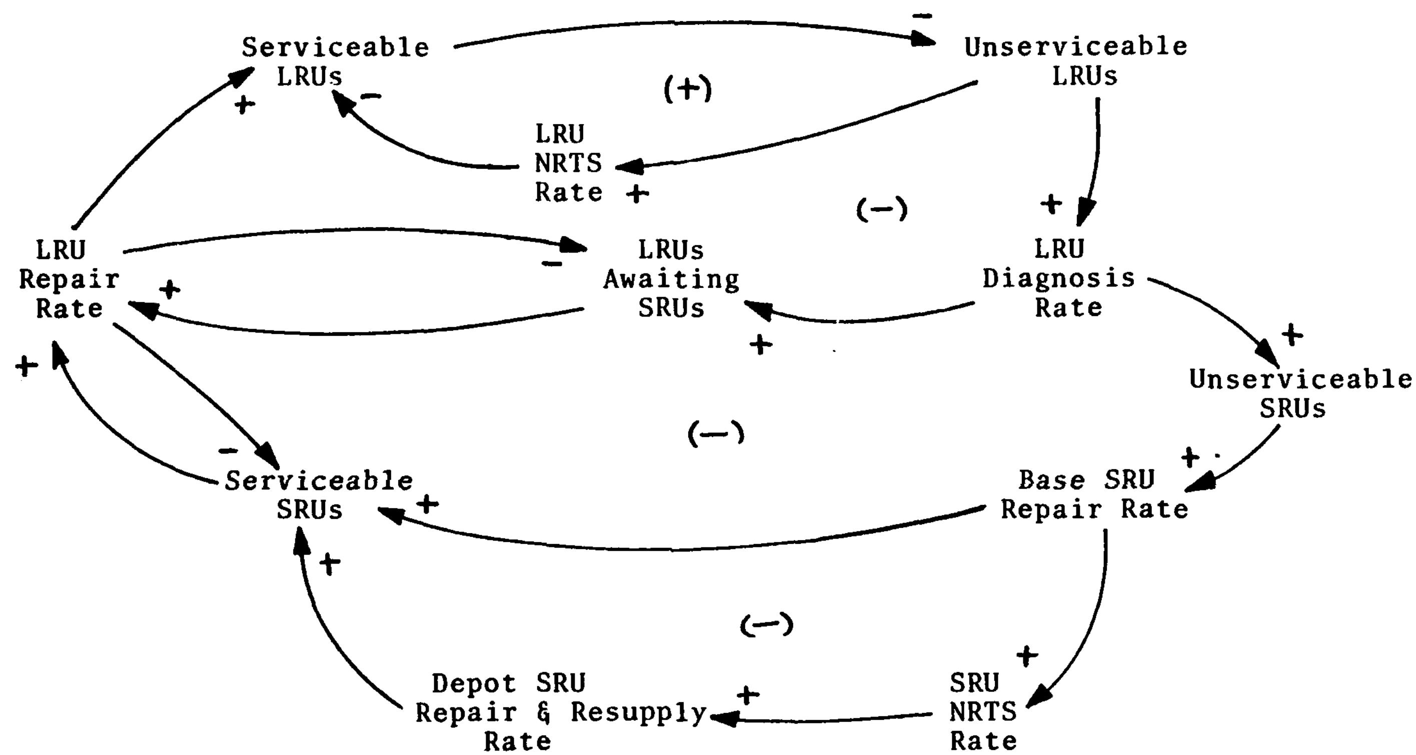

Figure 3-15

Causal-Loop Diagram for Base LRU and SRU Repair Process Sector

the LRU NRTS rate, and also the rate at which faulty LRUs are diagnosed. The changes in the diagnosis rate result in similar changes in the number of unserviceable LRUs awaiting replacement SRUs. Consequently, like changes occur in the number of unserviceable SRUs and the base-level SRU repair rate. Increases in the base SRU repair rate will increase the volume of serviceable SRUs and the SRU NRTS rate. In response to changes in the SRU NRTS rate, the depot SRU repair and resupply rate will also change in a like manner. Increases in the depot SRU resupply rate increase the base-level stocks of serviceable SRUs.

The increase in the number of LRUs awaiting replacement SRUs causes an increase in the LRU repair rate as maintenance personnel attempt to repair LRUs as quickly as possible. An additional consideration in the linkage between these two factors is the pressure to keep the level of LRUs awaiting SRUs at or near zero. It is easy and quick to make these LRUs serviceable by installing the required SRUs, if available. As a consequence, increases in the availability of serviceable SRUs from either base-level or depot-level actions will cause increases in the LRU repair rate. It is clear that the availability of serviceable SRUs could be one of the key limiting factors in the system.

Flow Diagram

The flow diagram for this sector (Figure 3-16) advances the idea that LRU and SRU repairs are parallel, interactive

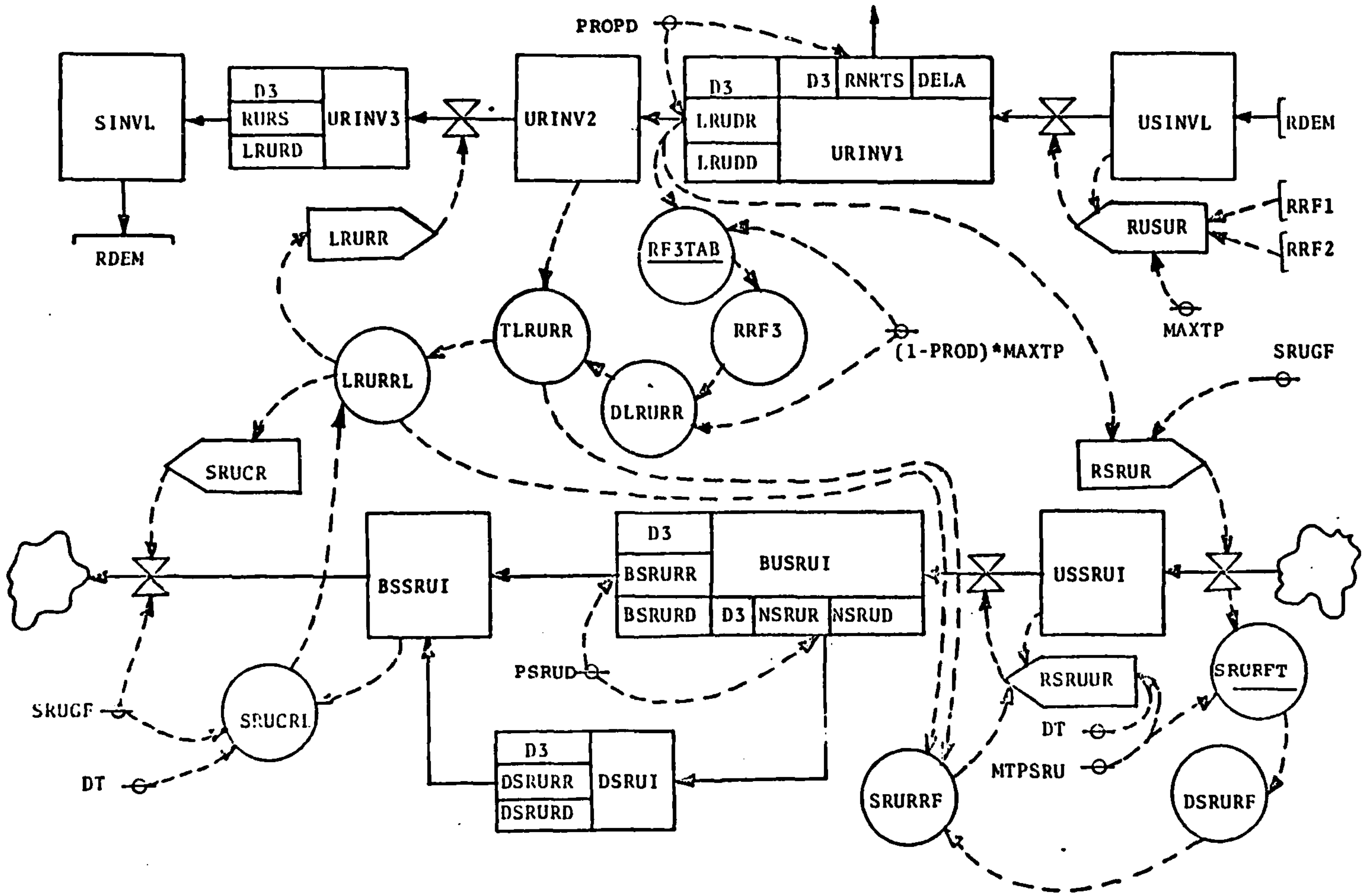

Figure 3-16

Flow Diagram for Base LRU and SRU Repair Process Sector

TABLE 3-5

Variables Appearing in Figure 3-16

USINVL	-	UNSERVICEABLE LRU INVENTORY (LRUS)
RDEM	-	RATE OF DEMAND (LRUS/WK)
DTDR	-	DIVERSION TO DEPOT RATE (LRUS/WK)
PDR	-	PERCEIVED DEMAND RATE (LRUS/WK)
UMRD	-	UNIT MAINTENANCE RESPONSE DELAY (WKS)
RRF1	-	REPAIR RATE FACTOR 1
RF1TAB	-	REPAIR RATE FACTOR 1 TABLE
RRF2	-	REPAIR RATE FACTOR 2
RF2TAB	-	REPAIR RATE FACTOR 2 TABLE
RAUF	-	REALIZED AIRCRAFT UTILIZATION FACTOR
DRUSUR	-	DESIRED RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
RUSUR	-	RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
MAXTP	-	MAXIMUM THROUGHPUT (LRUS/WK)
URINV1	-	UNDER REPAIR INVENTORY 1 (LRUS)
RNRTS	-	RATE LRUS DECLARED NRTS (LRUS/WK)
PROPD	-	PROPORTION OF LRUS TO DEPOT
DELA	-	DELAY FOR NRTS ASSESSMENT (WKS)
LRUDR	-	LRU DIAGNOSIS RATE (LRUS/WK)
LRUDD	-	LRU DIAGNOSIS DELAY (WKS)
URINV2	-	UNDER REPAIR INVENTORY 2 (LRUS AWAITING SRUS)
RRF3X	-	REPAIR RATE FACTOR 3 INDEX
RRF3	-	REPAIR RATE FACTOR 3
RF3TAB	-	REPAIR RATE FACTOR 3 TABLE
DLRURR	-	DESIRED LRU REPAIR RATE (LRUS/WK)
TLRURR	-	TRIAL LRU REPAIR RATE (LRUS/WK)
SRUCRL	-	SRU CONSUMPTION RATE LIMIT (SRUS/WK)
LRURRL	-	LRU REPAIR RATE LIMIT (LRUS/WK)
LRURR	-	LRU REPAIR RATE (LRUS/WK)
URINV3	-	UNDER REPAIR INVENTORY 3 (LRUS)
RURS	-	RATE AT WHICH UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)

TABLE 3-5, continued

LRURD	-	LRU REPAIR DELAY (WKS)
SINVL	-	SERVICEABLE INVENTORY OF LRUS (LRUS)
RARFD	-	RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
RAPFD	-	RATE OF ARRIVAL OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
BLRU	-	BASE LRU INVENTORY (LRUS)
RSRUR	-	REPAIRABLE SRU RATE (SRU/WK)
SRUGF	-	SRU GENERATION FACTOR (SRUS/LRU)
USSRUI	-	UNSERVICEABLE SRU INVENTORY (SRUS)
SRURFX	-	SRU REPAIR FACTOR INDEX
MTPSRU	-	MAXIMUM THROUGHPUT OF SRUS (SRUS/WK)
DSRURF	-	DESIRED SRU REPAIR FACTOR
SRURFT	-	SRU REPAIR FACTOR TABLE
SRURRF	-	SRU REPAIR RATE FACTOR
RSRUUR	-	RATE SRUS GO UNDER REPAIR (SRUS/WK)
BUSRUI	-	BASE UNSERVICEABLE SRU INVENTORY (SRUS)
NSRUR	-	RATE SRUS DECLARED NRTS (SRUS/WK)
PSRUD	-	PROPORTION OF SRUS TO DEPOT
NSRUD	-	NRTS SRU ASSESSMENT DELAY (WKS)
DSRUI	-	DEPOT SRU INVENTORY (SRUS)
DSRURR	-	DEPOT SRU REPAIR RATE (SRUS/WK)
DSRURD	-	DEPOT SRU REPAIR DELAY (WKS)
BSRURR	-	BASE SRU REPAIR RATE (SRUS/WK)
BSRURD	-	BASE SRU REPAIR DELAY (WKS)
BSSRUI	-	BASE SERVICEABLE SRU INVENTORY (SRUS)
BSSRU	-	BASE SRU STOCK (SRUS)
SRUCR	-	SRU CONSUMPTION RATE (SRUS/WK)

process in which the workload for the SRU repair process is generated by the diagnosis stage of the LRU process. The SRU source and sink symbols serve to highlight the fact that the flow of SRUs is physically distinct from the flow of LRUs, and that reparable SRUs are "created" as a consequence of the LRU diagnosis process, and repaired SRUs are subsequently consumed as a consequence of the LRU repair process. The LRU flow is described first.

As in the simple base repair sector development before, the combination of demand rate pressure (RRF1) and inventory pressure (RRF2) results in a rate at which unserviceable LRUs are drawn from unserviceable inventory for processing by the workshop (RUSUR). The first process LRUs undergo in the workshop is diagnosis. As a result, some LRUs are classified NRTS and exit the sector via the NRTS rate. All other LRUs are reparable at the base; after diagnosis their faulty SRUs are removed, and the LRUs are then transferred to the intermediate under repair inventory (URINV2) to await availability of replacement SRUs. Subject to the availability of replacement SRUs, the LRUs in this intermediate repair inventory are transferred into the repair process (URINV3) at a rate called the LRU repair rate (LRURR). The LRU repair rate is determined by an auxiliary structure which ties together information on the pressure to repair LRUs as quickly as they are diagnosed, the pressure to reduce any backlog in the intermediate repair inventory, and the limits of the availability of serviceable SRUs. The output of the repair process is the rate of flow of

serviceable LRUs back to serviceable inventory (RURS).

The diagnosis process is similar to the repair process in the simple LRU repair process sector, and has been represented as a combined third-order exponential delay. While the parameters for the NRTS rate remain the same as before, the delay factor (LRUDD) for the LRU diagnosis rate (LRUDR) is different since diagnosis is only part of the process represented by the repair delay in the previous sector. The specification of the delay factor for the diagnosis rate encompasses time actually spent to diagnose faults and remove faulty SRUs.

The repair process is also represented as a third-order exponential delay. The specification of the delay factor includes the time to install replacement SRUs, functional testing and adjustment, and all other repair actions determined by the diagnosis stage.

The remaining flow shown in Figure 3-16 is that of SRUs. The flow diagram illustrates that, as a consequence of the LRU diagnosis rate (LRUDR), a flow of reparable SRUs is generated (RSRUR). The relationship between the LRU diagnosis rate and the reparable SRU rate is developed in the discussion of the DYNAMO equations for this sector. The reparable SRUs accumulate in the base unserviceable SRU inventory (USSRUI). The rate at which these unserviceable SRUs enter the repair process (RSRUUR) is determined by two factors. First, there is the pressure on the maintenance shop to work harder because of the rate at which reparable SRUs are generated, and the effect this has on the backlog of work in the unserviceable SRU

inventory. The other factor is the pressure to work the SRU repair process at maximum capacity whenever the desired LRU repair rate cannot be achieved due to a shortage of serviceable SRUs.

The pressure caused by the rate that reparable SRUs undergo repair is represented by a pressure function similar to that for the demand pressure in the simple LRU process sector (RRF1, Figure 3-9). The representation of the pressure due to the desired LRU repair rate will be covered in the discussion of the DYNAMO equations for this sector.

The base SRU repair process is represented by a combination third-order delay similar to the one representing the diagnosis stage of the LRU repair process. The outputs from this process are serviceable SRUs to the base serviceable inventory, and NRTS SRUs to the depot SRU repair and resupply process. From base serviceable SRU inventory, SRUs flow to a sink at a rate determined by the rate that LRUs leave the intermediate repair inventory (awaiting SRUs) and enter the LRU repair process.

The depot repair and resupply process for NRTS SRUs is represented by a single, third-order delay. This is, of course, a highly aggregated representation. In practice, SRUs are part of the population of all reparable items and, therefore, have depot and support pipeline structures similar to that of LRUs. Consequently, detailed representation of the depot processing of SRUs would require a virtual duplication of the LRU processing structure. The purpose of the model,

however, is to investigate the LRU processing system; the level of aggregation employed here captures the principle interactions between LRUs and SRUs, and still provides the basis for more detailed representation. The simplification, therefore, seems justified.

DYNAMO Equations

The DYNAMO equations which create the flow of reparable SRUs, and consume serviceable SRUs as a function of the LRU repair process, are the basis of this sector. The basis for these equations is the SRU generation factor (SRUGF) shown in the flow diagram. Therefore, to facilitate the discussion of the DYNAMO equations for this sector, the derivation of SRUGF is discussed first.

If LRUs are assumed to contain only one SRU, an appropriate SRU generation factor can be obtained by measuring the number of SRU replacements per LRU processed during a number of statistically significant periods. The mean of the sampling distribution thus produced would provide a measure of the average number of SRU replacements per LRU processed through the workshop, and would be a value less than one, depending upon the probability of failure for the SRU. This mean could then be used as the SRU generation factor to produce a flow of reparable SRUs with a valid statistical relationship to the LRU diagnosis rate by multiplying the diagnosis rate (LRUDR) by the SRUGF. Conversely, the SRU consumption rate can be obtained by multiplying the rate at which LRUs awaiting

SRUs enter the LRU repair process (LRURR) by the SRUGF.

Having discussed how to derive the SRU generation factor for an LRU with a single SRU, the question remains of how to represent the more realistic situation of an LRU with several different SRUs. For the purposes of this research, it was considered necessary only to represent the interaction between the LRU and SRU repair processes in a manner which addressed the fundamental interactions and provided a basis for elaboration in subsequent research with the model. A composite SRU process flow satisfies this goal. To achieve this, it was assumed that the hypothetical avionics LRU which provided the basis for the model parameters contains five SRUs, and that all these SRUs have the same probability of failure and identical processing delay and NRTS percentage factors. Under this assumption the SRU process shown in the flow diagram represents a composite SRU flow for which the SRU generation factor is given by the sum of the individual SRU generation factors, or simply, five times the common individual SRUGF.

On the basis of the preceding discussion of the derivation and significance of the SRU generation factor in this sector, it is now possible to discuss the development of the DYNAMO equations for the sector in the sequence suggested by the flow diagram. The flow of LRUs is discussed first.

The equations for the repair rate factors RRF1 and RRF2, and the rate at which unserviceable LRUs undergo repair are identical to those in the LRU-only version of the base repair sector. Therefore, these equations are not repeated

here. They are, however, included in the composite listing for this sector (Appendix C, line numbers 3-1 to 3-11).

The equations for the LRU diagnosis process are similar to those for the base repair process in the previous sector:

```
L  URINV1.K=URINV1.J+DT*(RUSUR.JK-RNRTS.JK-LRUDR.JK)
N  URINV1=0
R  RNRTS.KL=DELAY3(PROPD*RUSUR.JK,DELA)
C  PROPD=0.2
C  DELA=0.3 WEEKS
R  LRUDR.KL=DELAY3((1-PROPD)*RUSUR.JK,LRUDD)
C  LRUDD=0.4 WEEKS
```

The choice of values for the parameters PROPD and DELA was explained in the discussion of the previous sector. The choice of 0.4 weeks for the LRU diagnosis delay (LRUDD) was made on the basis that, in general, the repair and adjustment of avionics LRUs takes longer than fault diagnosis. Therefore, the repair delay was set to 0.8 weeks. The sum of these two delays equates to the overall repair delay (DELR) of 1.2 weeks used in the previous repair sector.

The equation for the inventory of LRUs awaiting SRUs (URINV2) is simply given by the net effect of the input and output rates:

```
L  URINV2.K=URINV2.J+DT*(LRUDR.JK-LRURR.JK)
N  URINV2=0
```

The LRU repair rate is determined by an auxiliary structure that takes into account the pressure to repair LRUs

as they are diagnosed, the pressure to keep URINV2 near zero, and the constraint of serviceable SRU availability. The first two of these components is represented by a single table function which is similar to that for RRF1. Figure 3-17 shows the form of this function.

The figure illustrates that the combination of the pressure to repair LRUs as they are diagnosed and the pressure to keep URINV2 near zero will tend to keep the LRU repair rate (determined by RRF3) greater than the diagnosis rate (LRUDR). Hence the LRU repair rate (LRURR) will reach maximum before LRUDR does. The expression ((1-PROPD)*MAXTP) gives the maximum value for LRUDR. Note that this is not equal to the maximum throughput (MAXTP), as might be expected. This is because MAXTP includes the assessment of NRTS LRUs. The maximum value of LRUDR is limited to that proportion of the MAXTP that stays on base for repair. The shape of the function represents the initial lag in responding to changes and the resistance felt in approaching an upper limit, as discussed in the derivation of RRF1.

The equations to determine the LRU repair rate (LRURR) are:

```
A  RRF3X.K=LRUDR.JK/((1-PROPD)*MAXTP)
A  RRF3.K=TABHL(RF3TAB,RRF3X.K,0,1,.1)
T  RF3TAB=.625/.625/.625/.66/.71/.77/.83/.88/.95/.99/1.0
A  DLRURR.K=RRF3.K*(1-PROPD)*MAXTP
A  TLRURR.K=FIFGE(URINV2.K/DT,DLRURR.K,DLRURR.K,
                                 URINV2/DT
A  SURCRL.K=BSSRUI.K/DT
A  LRURRL.K=FIFGE(SRUCRL.K/SRUGF,TLRURR.K,TLRURR.K,
                                 SRUCL.K/SRUGF
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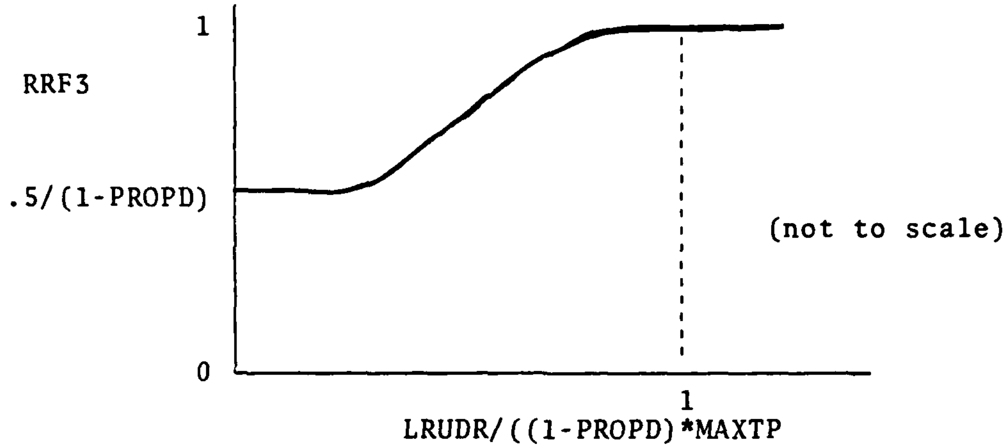


Figure 3-17

Derivation of Repair Rate Factor 3

R LRURR.KL=LRURRL.K

N LRURR=0

The first four equations provide RRF3 which, in turn, is used to produce the desired LRU repair rate (DLURR). This is the LRU repair rate that maintenance managers desire to establish as a consequence of the LRU diagnosis rate and the pressure to keep URINV2 near zero. As noted earlier, the LRU diagnosis rate (LRUDR) is limited to a maximum of (((1-PROPD)* MAXTP)) since this is the maximum proportion of the LRUs that undergo repair (RUSUR) that will remain on base for repair. Recalling that MAXTP is the design limitation of the maintenance shop, this logic can be extended to derive the maximum value of the desired LRU repair rate. Again, this must be ((1-PROPD)*MAXTP).

The shape of Figure 3-17 suggests that the DLRURR will always be greater than the LRUDR. This reflects the fact that

maintenance managers try to keep the URINV2 near or at zero. Thus, their DLRURR always exceeds the current value of the LRUDR by some factor. This factor is RRF3. When RRF3 is combined with the LRUDR, the DLRURR results.

The minimum value of the RRF3 table can also be derived by analogy to the RRF1 function. Recall that the maximum value of RRF1 was set at 0.5xMAXTP. This value represented the minimum natural rate at which LRUs would be processed in the absence of any pressure. This resulted in a minimum value for RUSUR of 1 per week. This minimum value for RRF3 represents this same minimum work rate in the absence of any pressure or inventory constraints. Therefore, the minimum value for RRF3 should result in a DLRURR of 1 per week also. Substituting in the equation for DLRURR, DLRURR=1, PROPD=0.2, and MAXTP=2, yields the minimum value of 0.625 for RRF3. A more general relationship for this minimum value is obtained by setting the equation for RUSUR equal to the equation for DLRURR, solving for RRF3 and substituting for the minimum value of RRF1 as shown:

DLRURR=RUSUR

and:

RRF3*(1-PROPD)*MAXTP=RRF1*MAXTP

Therefore:

RRF3=0.5/(1-PROPD)

This more general value is shown in Figure 3-17.

Once the DLRURR is determined, a check must be made of whether or not the level of LRUs awaiting SRUs (URINV2) can

sustain this rate over the upcoming solution interval. If not, LRURR will need to be set to that value which will just reduce URINV2 to zero by the end of the next solution interval. A trial LRU repair rate (TLRURR) auxiliary variable is used to achieve this. The practical significance of limiting LRURR in this way was discussed in the determination of RUSUR in the previous sector.

The final two equations in the determination of LRURR take into account the availability of serviceable SRUs. The SRU consumption rate limit (SRUCRL) is that rate which will just reduce the stock of serviceable SRUs (BSSRUI) to zero by the end of the upcoming solution interval. Hence, this rate is given by the value of BSSRUI at the beginning of the solution interval divided by the length of the solution interval (DT). When this value of SRUCRL is divided by the average number of SRUs replaced per repaired LRU (SRUGF), the maximum possible value for the LRU repair rate (LRURR) is obtained. This computation is incorporated in the equation for the LRU repair rate limit (LRURRL). The equation for LRURRL compares TLRURR with the maximum possible value for LRURR allowed by the availability of SRUs, and selects the lower value. The rate equation for LRURR then sets LRURR equal to LRURRL. Note that LRURR could have been computed more directly by eliminating the auxiliary variable LRURRL and setting LRURR equal to the right-hand side of the equation for LRURRL. The reason for the extra step is given in the discussion of the equation for the SRU consumption rate.

The final equations for the LRU process compute the under repair inventory in the repair process (URINV3) and the serviceable LRU output rate (RURS in the previous sector):

L URINV3.K=URINV3.J+DT*(LRURR.JK-RURS.JK)

N URINV3=0

R RURS.KL=DELAY3(LRURR.JK,LRURD)

C LRURD=0.8 WEEKS

The reason for choosing an LRU repair delay (LRURD) of 0.8 weeks was given in the earlier discussion of the LRU diagnosis delay. This completes the discussion of the equations for the processing of LRUs. The equations for the SRU process are presented next.

The description of the flow diagram indicated the manner in which a flow of reparable SRUs is generated as a consequence of the LRU diagnosis rate. The equations for this reparable SRU rate (RSRUR) and the inventory in which the reparable SRUs are accumulated (USSRUI) are:

R RSRUR.KL=LRUDR.JK*SRUGF

C SRUGF=2.5

L USSRUI.K=USSRUI.J+DT*(RSRUR.JK-RSRUUR.JK)

N USSRUI=0

Of these equations, only the choice of value for SRUGF requires further comment. Recalling that the LRUs were assumed to contain five SRUs with equal probability of failure, the value of 2.5 for SRUGF equates to an SRUGF of 0.5 for each of the SRUs. This implies that, on the average, each SRU is

replaced once for every two LRUs processed by the workshop, which is high in comparison to what would be expected for an LRU of the type on which the model parameters are based. The reason that a higher-than-normal value was chosen is given in the sensitivity analysis section of this research. It is sufficient to note at this point that the remaining parameters in the SRU process were chosen to be consistent with an SRUGF of 2.5, and that a realistic relationship between the LRU and SRU processes was maintained.

From USSRUI the SRUs enter the repair process at a rate which is equivalent to RUSUR for LRUs, and is therefore designated RSRUUR--the rate SRUs undergo repair. Because of the similarity between RSRUUR and RUSUR, the pressure function which relates RUSUR to the LRU demand rate (RDEM) is employed in the determination of RSRUUR. There is a second pressure component in the determination of RSRUUR. This pressure occurs when the availability of SRUs is limiting the desired LRU repair rate. In this situation there is a tendency to maintain the SRU production rate at maximum. This is accounted for by modifying the repair rate factor for RSRUUR. The equations for the complete decision process are:

```
A  SRURFX.K=RSRUR.JK/MTPSRU
C  MTPSRU=3    PER WEEK
A  DSRURF.K=TABHL(SRURFT,SRURFX.K,0,1,.1)
T  SRURFT=.5/.5/.53/.58/.65/.73/.82/.91/.97/.98/1.0
A  SRURRF.K=FIFZE(DSRURF.K,1,TLRURR.K-LRURRL.K)
```

```
R  RSRUUR.KL=FIFGE(USSRUI.K/DT,SRURRF.K*MTPSRU,
X                      SRURRF.K*MTPSRU,USSRUI.K/DT)
```

The reader should note that the first four of these equations are equivalent to those for RRF1 in the determination of RUSUR for LRUs. The use of the FIFZE macro in the equation for the SRU repair rate factor (SRURRF) incorporates the second pressure factor mentioned above. This equation sets SRURRF to the level determined by the pressure due to the rate reparable SRUs are being generated whenever the LRU repair rate is equal to TLRURR, that is, when the LRU repair rate is not limited by SRU availability. On the other hand, if SRU availability is limiting LRURR to less than desired, the equation sets SRURRF equal to 1.0. This results in the SRU process working at its maximum throughput capability (MTPSRU), which is equivalent to the MAXTP parameter in the LRU process. The equation for RSRUUR then sets the rate at the desired level or the level USSRUI can sustain, whichever is the lower.

With the exception of the SRU consumption rate, the remaining equations for the SRU process can be directly inferred from the flow diagram and require no additional explanation. The choice of the parameter values, as indicated above, is discussed in Chapter 5. The equations are:

```
L  BUSRUI.K=BUSRUI.J+DT*(RSRUUR.JK-NSRUR.JK-BSRURR.JK)
N  BUSRUI=0
R  NSRUR.KL=DELAY3(PSRUD*RSRUUR.JK,NSRUD)
C  PSRUD=0.2
```

```
C  NSRUD=0.5   WEEKS
R  DSRURR.KL=DELAY3(NSRUR.JK,DSRURD)
C  DSRURD=6   WEEKS
L  DSRUI.K=DSRUI.J+DT*(NSRUR.JK-DSRURR.JK)
N  DSRUI=0
R  BSRURR.KL=DELAY3((1-PSRUD)*RSRUUR.JK,BSRURD)
C  BSRURD=2   WEEKS. COMP TO 1.2 FOR LRUS
L  BSSRUI.K=BSSRUI.J+DT*(BSRURR.JK+DSRURR.JK-SRUCR.JK)
N  BSSRUI=BSRU
C  BSRU=15   3 SPARES FOR EACH TYPE
```

The final equation for the SRU process sets the SRU consumption rate as determined by the LRU repair rate:

```
R  SRUCR.KL=LRURRL.K*SRUGF
```

Note that this equation uses LRURRL and not LRURR when, in fact, LRURR and LRURRL are equal at all times. The reason for this lies in the DYNAMO conventions for computing the equations. DYNAMO always computes level equations first, then auxiliary equations, and finally rate equations. Additionally, the use of rate variables with KL time subscripts on the right-hand side of the rate equation is not allowed. This latter convention prevents the direct representation of the interaction of two or more rates which are instantaneously time dependent, as is the case with LRURR and SRUCR. During any solution interval the SRUCR is (LRURR*SRUGF), but to represent this requires an equation of the form SRUCR.KL=LRURR.KL*SRUGF, which is prohibited by the DYNAMO conventions. The

auxiliary variable LRURRL is used to overcome this problem by computing the KL value for LRURR first as an auxiliary variable (LRURRL), which is then used to synchronize the LRU repair rate and the corresponding SRU consumption rate.

This concludes the discussion of the base repair sector for the processing of LRUs and SRUs. A complete listing of the DYNAMO equation is in Appendix C, line numbers 3-1 to 3-62. This block of equations completely substitutes for the corresponding sector for LRUs only. This facilitates the interchange of these sectors as required by the user of the model.

Base Routine Requisition Process

Process Description

The base-level routine requisition process provides the normal link between the base and depot inventories of an LRU. Its goal is to insure that adequate numbers of an LRU are requisitioned from the depot in order to provide sufficient stock at base level to meet routine demands for the LRU. In effect, the routine requisition process compensates for losses from the total base-level population of an LRU which occur because of Not Reparable This Station (NRTS) actions. This compensation is accomplished by computing the pipeline quantities of LRUs that must be moving in the reparable asset system in order to support the base's recent demand and repair history for the LRU under consideration. Once the pipeline quantities are known, the safety level of uninstalled LRUs

that should be on hand can be derived. Requisitions are placed with the appropriate depot to make up shortfalls in the base serviceable stock. All things being equal, and in the absence of significant, long-term changes in either the LRU demand rate or the base repair capability, the system will create a requisition only in response to an LRU's being classified as NRTS.

Requisitions are tracked at both the base level and the depot level. Records of requisitions placed help base-level supply managers to monitor the reparable asset system performance and prevent "double-ordering" against a single requirement. Base level records of requisitions are maintained until satisfied by receipt of an LRU, or cancelled for some other reason. After transmission of the requisition to the depot, the requisition exists as a backorder on the depot LRU inventory until satisfied by shipment of an LRU from the depot. The level of backorders at the depot is considered an important measure of the response of the reparable asset system.

The base's stock-leveling and requisitioning processes described above are performed by the UNIVAC 1050-II base supply computer system. Based on records of transactions between base supply and other base-level actors in the reparable asset system, the computer maintains a current record of demand and repair rates as well as stock receipts. The computer also generates requisitions as necessary, and maintains records of the requisitions generated. Though the operation of the computer is essentially transparent to its users, base supply

managers may intervene as necessary or desired in the operation of the system.

Causal-Loop Diagram

Figure 3-18 is the causal-loop diagram of the base level routine requisition process sector.

As noted in the process description, the major influences on the routine requisition process are the LRU demand rate, the LRU repair rate, and the NRTS rate. Changes in the LRU demand rate cause similar changes in the daily demand rate. The daily demand rate is not, however, exactly the same as the LRU demand rate. Rather, it is the arithmetic average of at least 180 days LRU demand data. Longer periods are used for low-demand items. Thus, only significant and lasting changes in the LRU demand rate will affect the daily demand rate. At the same time, changes in the LRU demand rate, acting through the LRU repair and NRTS rates, effect changes in the level of serviceable LRUs. The nature of these changes is mediated by the percentage of unserviceable LRUs that the base is able to repair.

Routine requisitions are placed in response to the daily demand rate and the current level of serviceable LRUs. If the level of serviceables is insufficient to meet the current daily demand, a routine requisition is generated. This requisition, in turn, creates a depot backorder. In response to the backorders placed with the depot, the Item Manager causes a shipment to be made to the base placing the requisition.

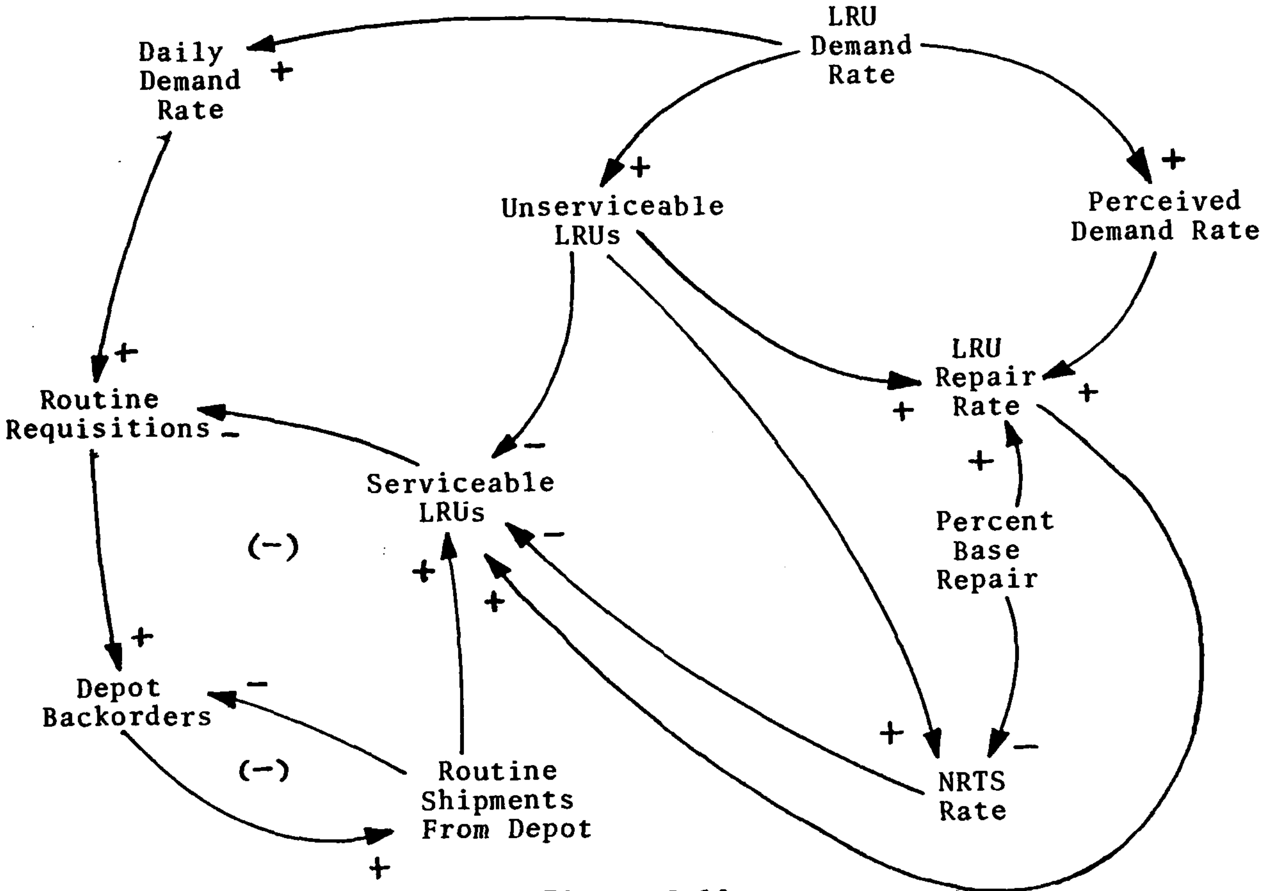


Figure 3-18

Causal-Loop Diagram of Base Level Routine Requisition Process Sector

Shipping an LRU to the requisitioning base reduces the pressure created by the backorder. Receipt of the new LRU at the base dampens the pressure at base level created by the imbalance between the daily demand rate and the level of serviceable LRUs. Note that due to the dampening influence of the level of serviceable LRUs on the routine requisitioning process, serviceable stock in excess of that justified by the daily demand rate will prevent requisitioning. This "self-leveling" nature of the LRU requisitioning process prevents the base from holding excess stock indefinitely.

Flow Diagrams

Because of the complexity of the computations in this sector, several flow diagrams have been used to represent the routine requisitioning process. Figure 3-19 shows the daily demand rate computation. In this process, a record is kept of the past 180 days' LRU demand rate (RDEM) data. This is then averaged to obtain the daily demand rate.

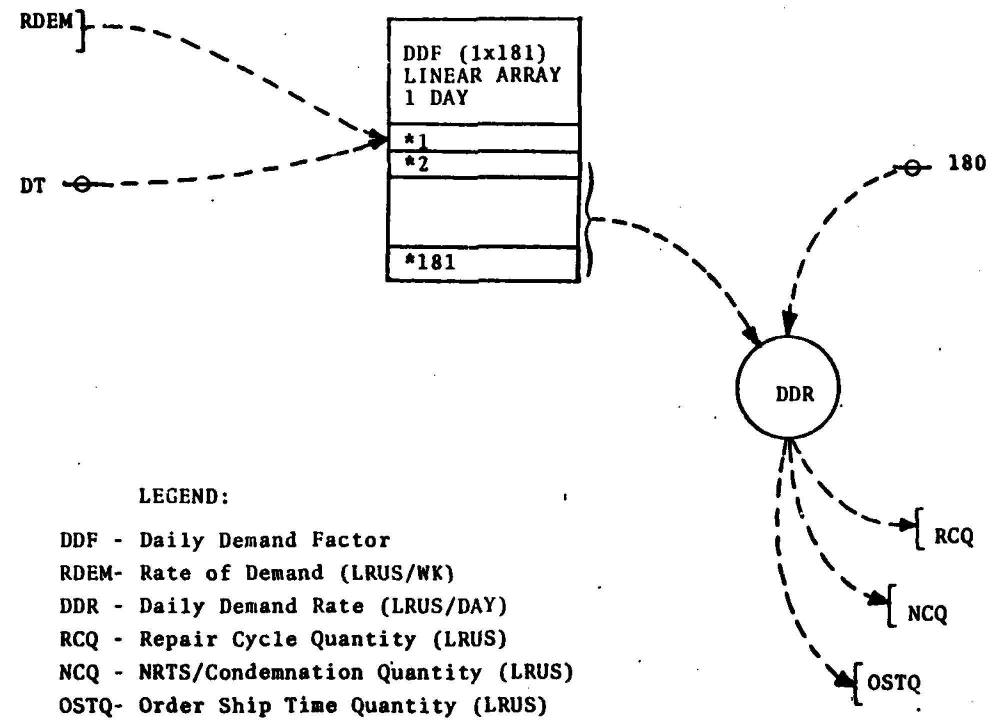
Figure 3-20 depicts the base repair rate computation. The percentage of base repair (PBR) is computed by the formula:

$$PBR = RTS/(RTS+NRTS)$$

where:

RTS = the number of "Reparable This Station:" that is, LRUs repaired at the base and returned to service

NRTS = the number of "Not Reparable This Station:" that is, LRUs not repaired at the base and,



LEGEND:

DDF - Daily Demand Factor
RDEM- Rate of Demand (LRUS/WK)
DDR - Daily Demand Rate (LRUS/DAY)
RCQ - Repair Cycle Quantity (LRUS)
NCQ - NRTS/Condemnation Quantity (LRUS)
OSTQ- Order Ship Time Quantity (LRUS)

Figure 3-19

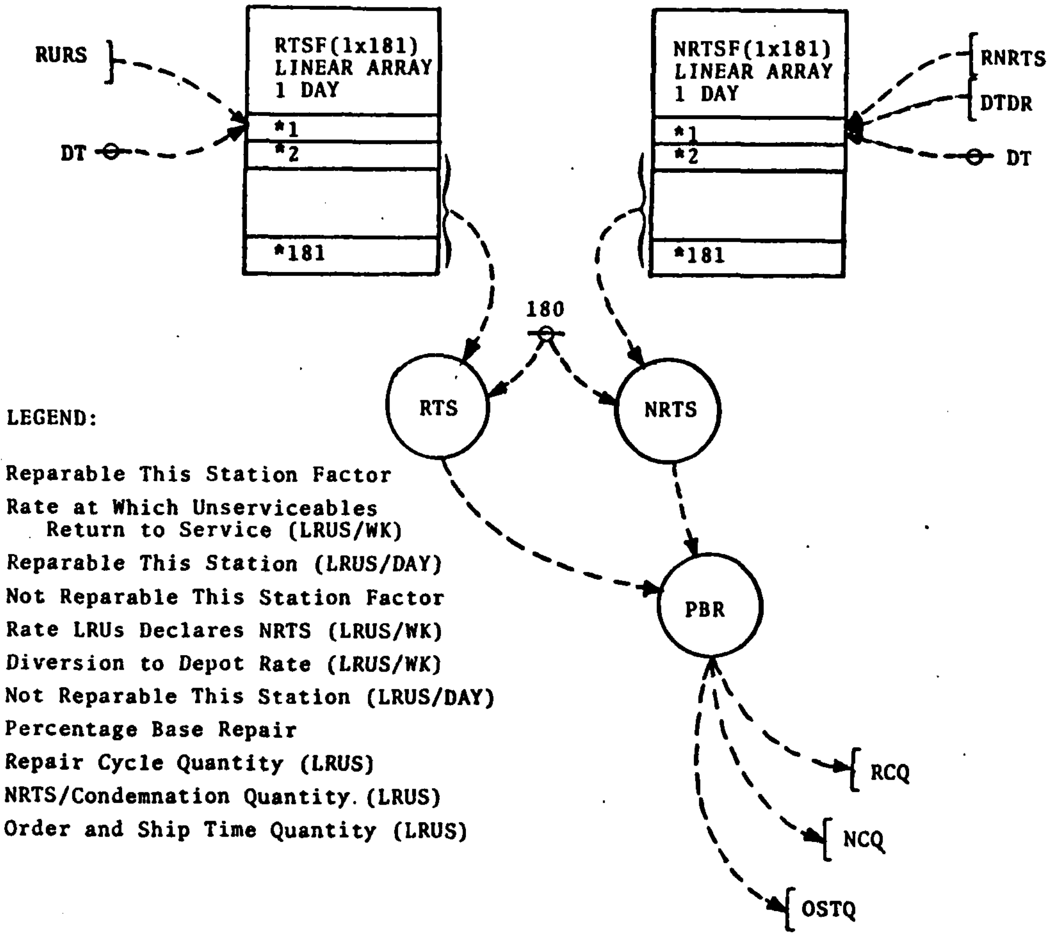
Flow Diagram for Daily Demand Rate Computation

therefore, returned to the depot for servicing. In this process, records are kept of the rate at which unserviceables are repaired and returned to service (RURS) and the rate at which unserviceables are not repaired at base level (RNRTS and DTDR). Note that the rate at which unserviceable LRUs are diverted to the depot (DTDR) must be included in this computation. This recognizes the fact that under certain extreme conditions, the item manager may direct that excess backlogs of unserviceable LRUs be diverted immediately to the depot rather than await assessment and possible repair at the base. These diverted LRUs are counted against the base's repair percentage in the same way as NRTS items. The diversion process will be discussed fully in the depot repair process sector that follows.

The RTS and NRTS values are computed by averaging the past 180 days of repair data. The percentage base repair is then computed.

Figure 3-21 and Table 3-6 show the computation of repair cycle pipeline quantities, the generation of requisitions and the placing of backorders at depot. Using the daily demand rate and the percent of base repair, three basic pipeline quantities are computed based on the standard process times associated with these pipelines. The first value is the repair cycle quantity (RCQ), representing the amount of LRU stock required to offset assets currently undergoing repair and destined to return to serviceable stock. The formula is:

$$RCQ = DDR \times PBR \times RCT$$



LEGEND:

RTSF - Reparable This Station Factor
RURS - Rate at Which Unserviceables Return to Service (LRUS/WK)
RTS - Reparable This Station (LRUS/DAY)
NRTSF- Not Reparable This Station Factor
RNRTS- Rate LRUs Declares NRTS (LRUS/WK)
DTDR - Diversion to Depot Rate (LRUS/WK)
NRTS - Not Reparable This Station (LRUS/DAY)
PBR - Percentage Base Repair
RCQ - Repair Cycle Quantity (LRUS)
NCQ - NRTS/Condemnation Quantity (LRUS)
OSTQ - Order and Ship Time Quantity (LRUS)

Figure 3-20
Flow Diagram for Repair Rate Computation

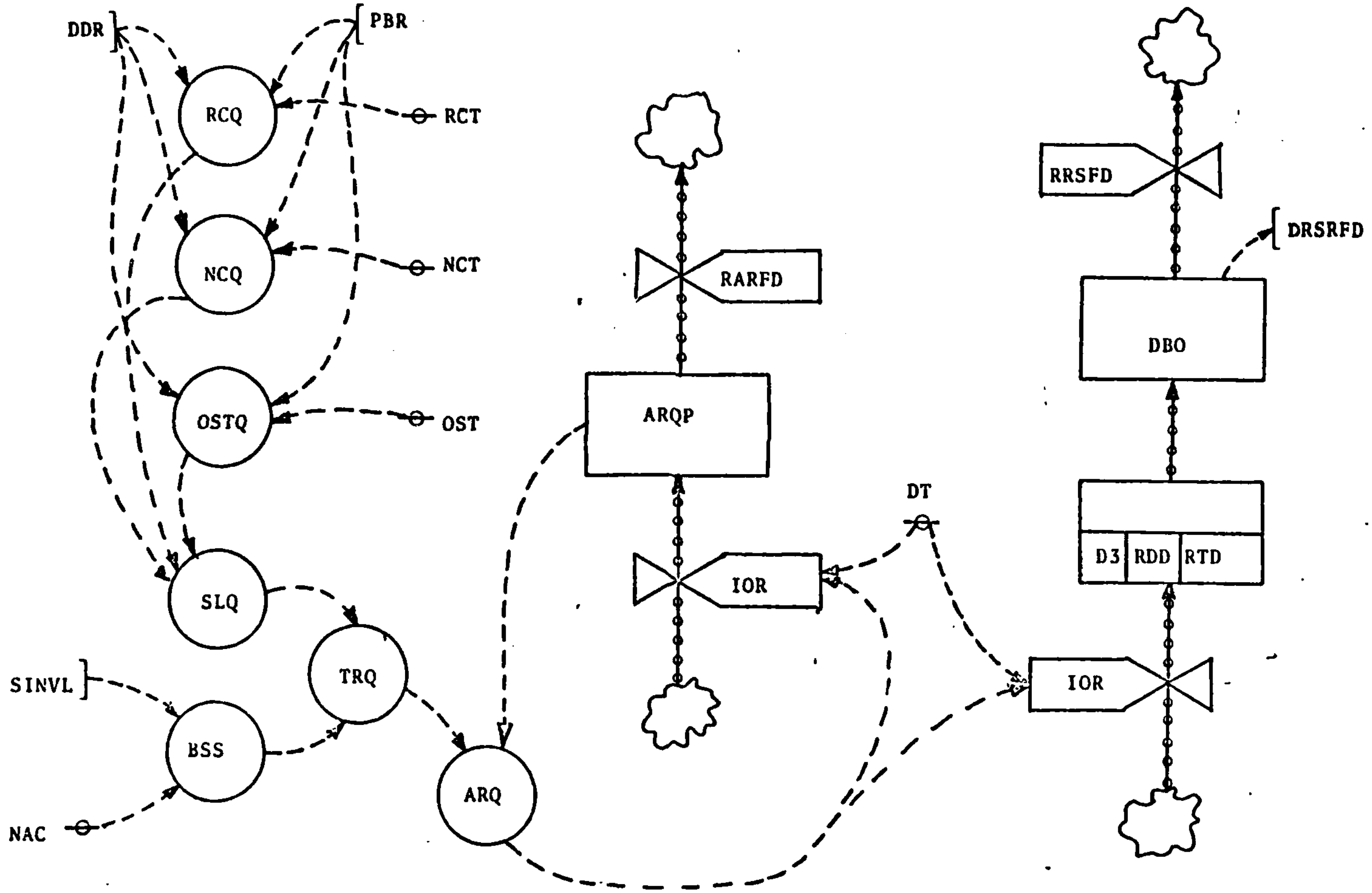


Figure 3-21

Flow Diagram for Repair Cycle Quantities, Requisitions and Depot Backorders

TABLE 3-6

Variables Appearing in Figure 3-21

RCQ	-	REPAIR CYCLE QUANTITY (LRUS)
DDR	-	DAILY DEMAND RATE (LRUS/DAY)
PBR	-	PERCENTAGE BASE REPAIR
RCT	-	REPAIR CYCLE TIME (DAYS)
NCQ	-	NRTS/CONDEMNED QUANTITY (LRUS)
NCT	-	NRTS/CONDEMNED ASSESSMENT TIME (DAYS)
OSTQ	-	ORDER AND SHIP TIME QUANTITY (LRUS)
OST	-	ORDER AND SHIP TIME (DAYS)
SLQ	-	SAFETY LEVEL QUANTITY (LRUS)
BSS	-	BASE SERVICEABLE STOCK (LRUS)
SINVL	-	SERVICEABLE INVENTORY OF LRUS (LRUS)
NAC	-	NUMBER OF AIRCRAFT (UNITS)
TRQ	-	TRIAL REQUISITION QUANTITY (LRUS)
ARQP	-	ACTUAL REQUISITIONS PLACED WITH DEPOT (ORDERS)
RARFD	-	RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
ARQ	-	ACTUAL REQUISITION QUANTITY (LRUS)
IOR	-	INSTANTANEOUS ORDER RATE (LRU ORDERS/WK)
RDD	-	REQUISITION DELAY TO DEPOT (ORDERS/WK)
RTD	-	REQUISITION TRANSMISSION DELAY (WKS)
DBO	-	DEPOT BACK ORDERS (ORDERS)
RRSFD	-	RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)

The repair cycle time (RCT) is the average time required to repair an LRU. The second value is the NRTS/condemnation quantity (NCQ). This is the amount of LRU stock required to offset assets currently undergoing repair assessment and expected to be declared NRTS or condemned. The formula is:

$$NCQ = DDR \times (1-PBR) \times NCT$$

The NRTS/condemnation time (NCT) is the average time required to assess an LRU as NRTS or to condemn it. The third value is the order and ship time quantity (OSTQ). This represents the amount of LRU stock required to offset the time lag between the placing of a requisition and its receipt via routine transportation modes. The formula is:

$$OSTQ = DDR \times PBR \times OST$$

The order and ship time (OST) is the average time required to requisition, ship, and receive an LRU.

Once the three pipeline quantities are known, it is possible to compute the safety level quantity (SLQ). This is the amount of uninstalled, serviceable LRU stock that ought to be on-hand at base level to support the current LRU demand rate. The formula is:

$$SLQ = C\sqrt{3 \times (RCQ+NCQ+OSTQ}$$

The quantity "C" represents a constant used to provide varying levels of supply support (fill rates) for different LRUs, depending on their criticality. Except in extraordinary situations, this value is always one.

Requisitions are placed whenever the base serviceable stock (BSS) falls below the safety level quantity (SLQ). Base serviceable stock is defined as actual, uninstalled serviceable LRUs. Stock to cover shortfalls in the SLQ will be ordered if a requisition to fill that shortfall has not already been placed. Thus, in any time period, only the stock required to cover new shortages is ordered. This process is represented by the trial requisition quantity (TRQ) and actual requisition quantity (ARQ), auxiliaries in Figure 3-21.

As noted in the process description, requisitions are monitored at both the base and depot. In the flow diagram this is represented by the flow of orders through the levels of actual requisitions placed (ARQP) and depot backorders (DBO). Orders are created by the instantaneous order rate (IOR) which takes the actual requisition quantity and enters it into the two flows over the next solution interval.

At the base level the requisitions remain on record (in the level ARQP) until a corresponding routine shipment is received (represented by the outflow rate of routine arrivals from depot, RARFD). Information about the level of requisitions placed is used in deciding what portion of the trial requisition quantity (TRQ) will actually be requisitioned.

Once a requisition is placed, there is a short delay before it is received and validated and enters into the depot backorder level (DBO). This requisition delay at depot (RRD) is represented by a third-order exponential delay. The requisition transmission delay (RTD) represents the standard total

time required to submit, pass on, and process an LRU against a requisition at depot level. Once requisitions enter the depot backorder level, they remain there until a shipment is made from depot to meet that backorder (represented by the rate of routine shipments from depot, RRSFD). Information about the level of backorders is used in determining the trial routine shipment rate from depot (TRSRFD).

DYNAMO Equations

The DYNAMO equations for this sector follow directly from the flow diagram. In order to simulate the arithmetic averaging of demand and repair data, the array manipulation functions of DYNAMO were used. In each case, a 1-by-181 element array was created to collect the information on the number of LRUs demanded, repaired, or declared NRTS. All elements of the array were initialized to values consistent with the hypothetical LRU under consideration. During each "day" of model time, information on the total number of LRUs demanded, repaired, or declared NRTS was loaded into the first element of the array. Information concerning the total number of LRUs in each class over the previous 180 days' of model time was obtained by taking the vector sum (SUMV) of elements 2 through 181 of the appropriate array. This value was then averaged to obtain the current value of the daily demand rate (DDR), the proportion of LRUs repaired (RTS), and the proportion of LRUs not repaired (NRTS). Once each "day" of model time was obtained, the shift linear (SHIFTL) function was used to discard

the 181st element, move the value of the ith element to the (i+1)th element, and set the first element to zero. For example, the daily demand rate (Figure 3-19) is derived as follows:

```
FOR  I=1, 181
L    DDF.K(1)=DDF.J(1)+DT*RDEM.JK
N    DDF(I)=0.2
A    DDR.K=SUMV(DDF.K,2,181)/180
S    LLD.K=SHIFTL(DDF.K,.15)
```

DDF = daily demand factor array LRUs/day

RDEM = LRU demand rate LRUs/week

DDR = daily demand rate LRUs/day

LDD = supplementary equation to move daily demand factor array ahead each day (= .15 week)

The total set of equations for the daily demand rate and the percentage of base repair can be found in Appendix C, line numbers 4-1 to 4-14. Note that in each case the variables DDR, RTS, and NRTS are in units of LRUs/day due to the daily shifting of the arrays. Because of this, the pipeline times in the repair cycle quantity equations (Appendix C, line numbers 4-15 to 4-21) must be expressed in days. Since the time units cancel out in these equations, this does not require any correction when the values for RCQ, NCQ, and OSTQ are used to compute SLQ. For example:

```
A  RCQ.K=(DDR.K*PBR.K*RCT)
C  RCT=7.5  DAYS
```

RCQ = repair cycle quantity   LRUs

DDR = daily demand rate   LRUs/day

PBR = percent base repair   dimensionless

Base serviceable stock (BSS) represents any serviceable LRUs which are not installed on aircraft. Since we have assumed in this model that one of the goals of the system is to maximize the availability of operational aircraft, base serviceable stock will only exist when all aircraft assigned to the flying unit (NAC) have the LRU under consideration installed. Thus, base serviceable stock is equal to the positive difference between the value of serviceable inventory (SINVL) and the number of aircraft (NAC). The MAX function achieves this:

```
A  BSS.K=MAX(0,(SINVL.K-NAC))
```

The trial requisition quantity (TRQ) represents the positive difference between the safety level quantity (SLQ) and BSS:

```
A  TRQ.K=MAX(0,(SLQ.K-BSS.K))
```

As noted above, the base supply system is programmed to prevent double ordering. Thus, at any time the number of actual requisition (ARQ) will equal only the increases in the trial requisition quantity over the actual requisitions placed (ARQP):

```
A  ARQ.K=MAX(0,(TRQ.K-ARQP.K))
```

Due to the continuous nature of the model, the

instantaneous order rate (IOR) is equal to the actual requisition quantity divided over the solution interval.

R IOR.KL=ARQ.K/DT

The instantaneous order rate is used to initiate the base and depot order flows. The base-level actual requisitions placed (ARQP) is computed by calculating the net effect over time of the input rate (IOR) and the output rate of routine arrivals from the depot (RARFD):

L ARQP.K=ARQP.J+DT*(IOR.JK-RARFD.JK)

Requisitions are subject to a short transmission and processing delay prior to entering the depot backorder level. This is simulated with a third-order exponential delay:

R RDD.KL=DELAY3(IOR.JK,RDT)

C RTD=.4 WEEKS

The requisition delay at depot (RDD) is the effective arrival rate of requisitions at the depot. The requisition transmission delay (RTD) is the average time of requisition transmission and processing. The depot backorder level is computed by calculating the net effect over time of the input rate (RDD) and the output rate of routine shipments from the depot (RRSFD):

L DBO.K=DBO.J+DT*(RDD.JK-RRSFD.JK)

This completes the discussion of the base-level routine requisition process sector. The consolidated DYNAMO equations are found in Appendix C, line numbers 4-1 to 4-31. In summary, this process provides the normal link between the

base and depot inventories of an LRU. Based on the routine daily demand rate, this process determines the amount of uninstalled base-level serviceable stock that should be on hand to support the reparable asset process, and requisitions the shortfalls between this desired level of stock and the actual level of stock on hand. The requisitions are tracked at both base and depot level. At base-level, this requisition record prevents over-ordering. At depot-level the backorders created when requisitions are received create pressure on the item manager to satisfy the requisitions placed from base level. The level of backorders is considered to be a measure of the effectiveness of the depot.

This sector also completes the development of the base-level sectors of the model. The remaining two process sectors examine the depot-level processes of the reparable asset system.

Depot Repair Process Sector

Process Description

The depot repair process sector consists of the following sub-processes:

1. the return of unserviceable LRUs from base to depot level for repair;

2. the repair of unserviceable LRUs which returns them to the depot inventory of serviceable LRUs;

3. the condemnation of LRUs beyond economical repair; and

4. the acquisition of new LRUs to replace those lost through condemnation.

The goal of the depot repair process is to provide sufficient stocks of serviceable LRUs at depot level to support both routine and priority requisitions at base level.

When it is determined that an unserviceable LRU will not be repaired at the base level, the component is returned to the depot for repair. At the depot the unserviceable LRUs are assessed and either condemned or repaired. The delay in repairing unserviceable LRUs at base level is a function of both the repair time itself and any delay encountered before the LRU enters the repair process. This latter delay is, in turn, a function of depot requirements for the LRU. If the depot serviceable inventory is low compared to projected requirements, then the item manager responsible for the LRU in question will reduce the amount of time a component waits for repair. Conversely, if depot serviceable stocks are high, the item manager may defer repair of an LRU. This variable depot repair delay also reflects the fact that different LRUs compete for technical repair center capability in much the same way as they do at base level. Thus, some delay in initiating repair on an LRU class may result in some economies of scale in the depot repair process.

Some LRUs will be beyond economical repair when they arrive at the depot and, therefore, will be condemned and leave the system. In turn, new assets are acquired from commercial suppliers to replace the condemned assets and to meet any new

requirements. The newly-acquired LRUs enter the system after a production leadtime delay.

Causal-Loop Diagram

Figure 3-22 is the causal-loop diagram for the depot repair process. Considering the Not Reparable This Station (NRTS) rate first, as it increases the depot repair rate must also increase, or eventually shortages will occur at the base level. The increase in depot repair rate leads to an increase in the depot serviceable inventory. If the depot serviceable inventory is at or near the desired level, there will be a tendency to reduce depot repair rate, in order not to exceed the desired level. Similarly, if the depot serviceable inventory should drop below the desired level, this will create pressure to increase the depot repair rate so as to restore the desired level of serviceable stock.

This causality will apply under normal operating conditions. If, however, the base should experience a sustained overload of its maintenance capability, the level of unserviceable inventory will increase steadily. Though this is an extremely rare occurrence, the reparable asset system managers interviewed identified several situations in which the levels of unserviceable stock at base level would be considered excessive. In this situation there would be growing pressure within the reparable asset system to divert some of this excess backlog to the depot for repair. This diversion to depot would take place to prevent expensive and scarce assets

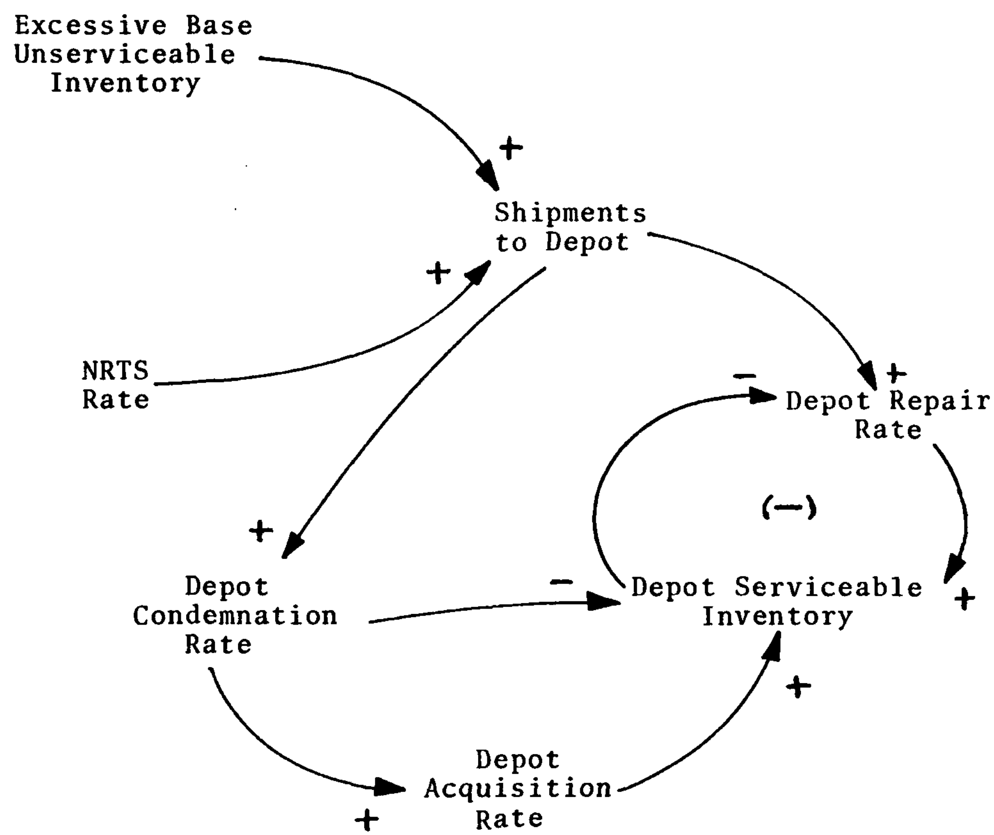


Figure 3-22

Depot Repair Process Sector Causal-Loop Diagram

from laying idle while awaiting repair. These diverted LRUs would then combine with the NRTS shipments to form the shipments-to-depot factor in the causal loop diagram.

The depot condemnation rate would also be affected by increased shipments to the depot, and thereby lower the depot serviceable inventory. Shortages created by condemnations would be made up by acquisition of the required number of items.

Flow Diagram

The flow diagram of the depot repair process sector (Figure 3-23; Table 3-7) was developed from the process description and causal relationships presented above.

The depot unserviceable inventory (DUI) is fed by the NRTS rate (RNRTS) and the diversion to depot rate (DTDR) of unserviceable LRUs. Note that the diversion rate is limited by the NRTS rate and the depot maximum throughput capability (DMAXTP).

The depot assessment and repair process is represented by two third-order exponential delays. The depot repair rate (DDR) has a variable average delay (DRD) determined by the depot serviceable inventory (DSI). This simulates the impact of requirements determination on the depot repair process.

The depot condemnation rate (DCR) is a constant proportion (PROPC) of the unserviceable reparable assets evaluated at the depot. In practice, condemnations occasionally take place at base level. However, the complexity of modern LRUs

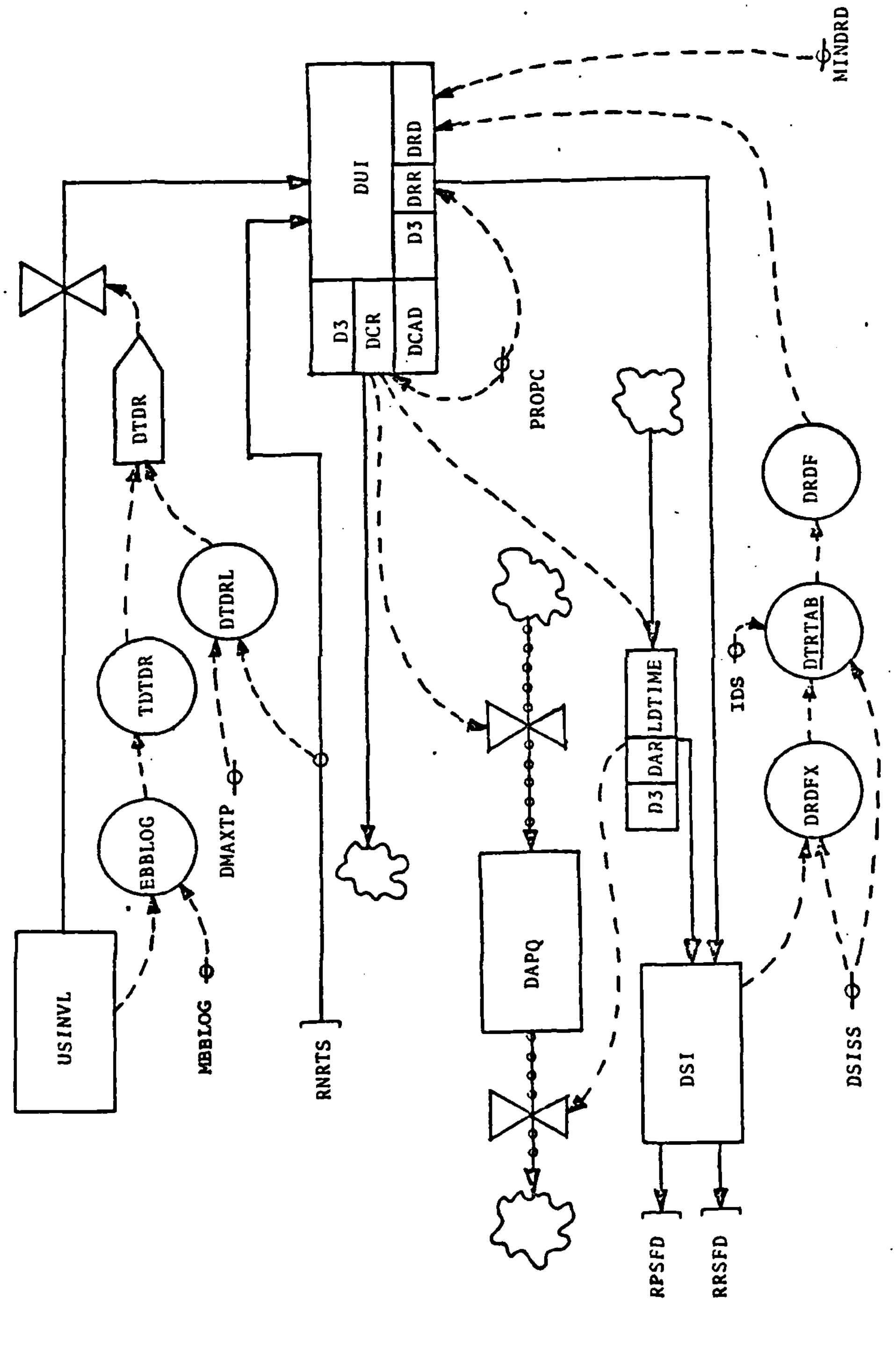


Figure 3-23

Flow Diagram for Depot Repair Process Sector

TABLE 3-7

Variables Appearing in Figure 3-23

EBBLOG	- EXCESS BASE MAINTENANCE BACKLOG (LRUS)
USINVL	- UNSERVICEABLE LRU INVENTORY (LRUS)
MBBLOG	- MAXIMUM BASE MAINTENANCE BACKLOG (LRUS)
TDTDR	- TRIAL DIVERSION TO DEPOT RATE (LRUS/WK)
DTDRL	- DIVERSION TO DEPOT RATE LIMIT (LRUS/WK)
DMAXTP	- DEPOT MAXIMUM REPAIR THROUGHPUT (LRUS/WK)
RNRTS	- RATE LRUS DECLARED NRTS (LRUS/WK)
DTDR	- DIVERSION TO DEPOT RATE (LRUS/WK)
DUI	- DEPOT UNSERVICEABLE INVENTORY (LRUS)
DRR	- DEPOT REPAIR RATE (LRUS/WK)
PROPC	- PROPORTION CONDEMNED
DRDFX	- DEPOT REPAIR DELAY FACTOR INDEX
DRDF	- DEPOT REPAIR DELAY FACTOR
DRDTAB	- DEPOT REPAIR DELAY TABLE
IDS	- INITIAL DEPOT STOCK (LRUS)
DSISS	- DEPOT SERVICEABLE INVENTORY SAFETY STOCK (LRUS)
DRD	- DEPOT REPAIR DELAY (WKS)
MINDRD	- MINIMUM DEPOT REPAIR DELAY (WKS)
DCR	- DEPOT CONDEMNATION RATE (LRUS/WK)
DAPQ	- DEPOT ACQUISITION PIPELINE QUANTITY (LRUS)
DCAD	- DEPOT CONDEMNATION ASSESSMENT DELAY (WKS)
DAR	- DEPOT ACQUISITION RATE (LRUS/WK)
LDTIME	- ACQUISITION LEAD TIME (WKS)
DSI	- DEPOT SERVICEABLE INVENTORY (LRUS)
RRSFD	- RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
RPSFD	- RATE OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)

generally makes the determination of economic repair a depot-level process. This fact, combined with the extremely small proportion condemned (less than 5 percent per year), led to the representation of all condemnations as a depot-level process.

Force size, funding, and industrial capacity are among the many factors that combine to determine the depot acquisition rate (DAR). At a basic level of analysis, though, the depot acquisition rate must replace those assets which leave the system through condemnations. Since acquisition is not an instantaneous process, but rather requires at least some leadtime before the new assets enter the system, the depot acquisition process is represented by a third-order exponential delay in which the average delay (LDTIME) is the average leadtime required for acquisition of LRUs, including any time delays that occur between condemnation and ordering. For simplicity, we have assumed that all condemnations will be reordered eventually.

DYNAMO Equations

The DYNAMO equations for this sector follow directly from the flow diagram. Three processes are represented: the determination of the diversion to depot rate; the determination of the variable depot repair delay; and the determination of the depot condemnation and acquisition rates.

As noted in the discussions above, the diversion to depot of LRUs directly from the base unserviceable inventory

is not expected to occur until the base repair backlog has reached some critical level. This level was defined as the Maximum Base Backlog (MBBLOG). Initially, this value was set to 13 units, which represents the amount of stock that could be repaired at maximum base repair effort in the depot turn-around time of 6.5 weeks. Hence:

C MBBLOG=13

LRUs in excess of this maximum backlog would be considered for shipment to the depot for repair. There is, however, a limit to the number of extra LRUs the depot can accept. This limit is defined as the depot maximum throughput (DMAXTP) and has the same meaning as the base MAXTP. That is, DMAXTP is the realistic maximum processing rate achievable with current resources. Initially, this limit was set to twice the maximum NRTS rate (i.e., 2 x PROPD x MAXTP = 0.8). The diversion to depot rate (DTDR) is limited, then, to the difference between DMAXTP and the NRTS rate. This limit is expressed:

A DTDRL.K=DMAXTP-RNRTS.JK

Once the DTDRL has been established, this limit is used to determine the actual DTDR. The equations are:

A EBBLOG.K=((USINVL.K-MBBLOG),0)

A TDTDR.K=EBBLOG/DT

R DTDR.KL=FIFGE(DTDRL.K,TDTDR.K,TDTDR.K,DTDRL.K)

The first equation determines the maximum amount which could be diverted to the depot. The MAX macro will set the excess

base backlog (EBBLOG) to zero if the base-level unserviceable inventory (USINVL) is less than the maximum base backlog (MBBLOG), that is, no diversion to depot is required. The next equation determines a trial diversion to depot rate (TDTDR). This rate will be used if it is less than the diversion rate limit (DTDRL). The last equation sets the actual value of DTDR. The FIFGE macro sets DTDR to the smaller of the TDTRR and DTDRL.

The depot repair process is represented as a third-order exponential delay of variable average delay. This depot repair delay (DRD) encompasses all of the processing of LRUs from the moment the decision is made to ship them from the base to the depot for repair, until they become available in the depot serviceable inventory for subsequent return shipment to the base level. As noted in the preceding discussion, the length of the repair delay is a function of the depot serviceable inventory. The nature of this relationship is shown in Figure 3-24. In this figure, the average depot repair delay factor (DRDF) is set equal to a value between its minimum and maximum limits, depending on the ratio of the level of the depot serviceable inventory (DSI) to the safety stock level (DSISS) for that inventory. A variation of one to three times the minimum depot repair rate (MINDRD) was assumed for the depot repair delay, thus the DRDF is varied between one and three. This appears to be a realistic range of flexibility for the depot repair delay when the large number of processes and processing times is considered. The

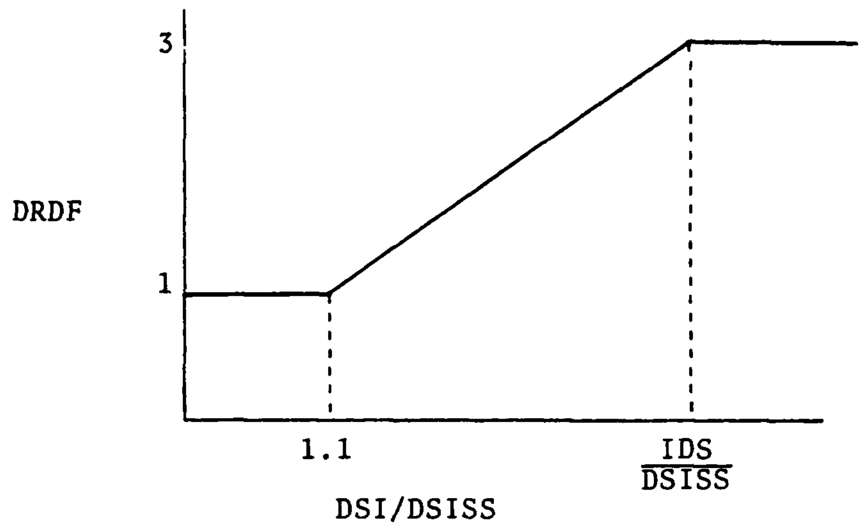


Figure 3-24

Derivation of Depot Repair Delay Factor

repair delay is set to its maximum (i.e., DRDF = 3) when the depot serviceable inventory (DSI) is greater than or equal to the initial depot stock (IDS) level. The initial depot stock is that level of components which should be in the depot serviceable inventory to support routine requisitions and priority requisitions. Above this level, there would be negligible pressure on the item manager to maintain any but the lowest possible repair rate. The DRDF decreases as the ratio of DSI to DSISS decreases, until the ratio assumes the value of 1.1. At this point the depot serviceable inventory is only ten percent above the safety stock level. Setting the lower limit of DRDF above the safety stock level in this way acknowledges the fact that, in practice, the item manager will respond to decreasing depot serviceable inventory levels in a manner which would result in a minimum depot repair delay some time before the safety

stock level is penetrated.

The relationships expressed in Figure 3-24 were implemented in the model by means of a table function (DRDTAB). The constants in the following equations were set with respect to the other levels and parameters in the model, and appear to be reasonable for a single-base, single-item model. The equations are:

```
A  DRDFX.K=DSI.K/DSISS
A  DRDF.K=TABHL(DRDTAB,DRDFX.K,1.1,IDS/DSISS,
                (IDS/DSISS)-1.1)
T  DRDTAB=1/3
A  DRD.K=DRDF.K*MINDRD
C  DSISS=2
C  IDS=10
C  MINDRD=2
```

The actual depot repair rate is implemented with a DELAY3 macro:

```
R  DRR.KL=DELAY3(((1-PROPC)*(RNRTS.JK+DTDR.JK)),DRD.K)
```

Note that the unserviceable LRUs arriving at the depot are apportioned between the depot repair rate and the depot condemnation rate (DRD) based on the proportion condemned (PROPC):

```
R  DCR.KL=DELAY3(PROPC*(RNRTS.JK+DTDR.JK),DCAD)
```

The depot condemnation assessment delay (DCAD) is the average time required to transport an LRU to depot and to determine whether it is economically reparable.

As noted in the preceding discussions, the depot

acquisition rate (DAR) is a function of the depot condemnation rate (DCR) and the acquisition leadtime (LDTIME):

R DAR.KL=DELAY3(DCR.JK,LDTIME)

The acquisition leadtime was set at 80 weeks to reflect average leadtime for reacquisition of complex electrical spare parts.

Note in Figure 3-24 that there is a flow of orders through the depot acquisition pipeline quantity (DAPQ). This reflects the number of LRUs on order by the depot, but not yet received into depot serviceable inventory. The level is computed as the net result of the depot condemnation and acquisition rates:

L DAPQ.K=DAPQ.J+DT*(DCR.JK-DAR.JK)

The depot serviceable inventory is determined in the usual manner:

L DSI.K=DSI.J+DT*(DRR.JK+(DAR.JK-RRSFD.JK-RPSFD.JK)

The input rates to this level, DRR and DAR, have been determined in this sector. The output rates of routine shipments from depot (RRSFD) and priority shipments from depot (RPSFD) will be developed in the next.

The consolidated listing of DYNAMO equations is found in Appendix C, line numbers 5-1 to 5-25. In summary, the depot repair process accepts as input those LRUs that are beyond the repair capabilities of the base because of either qualitative or quantitative reasons. These components are then assessed

and repaired or condemned. The repair rate can vary depending on the existing requirements for the LRU in question. Ultimately the goal of the system is to either repair or acquire sufficient stock of an LRU to meet both routine and priority demands for the stock. The final sector of the model will describe the process used at the depot to ascertain and meet those demands.

Depot Resupply Process Sector

Process Description

The depot resupply process has two major components: priority and routine shipments from depot. Taken together with the base level routine requisition process, the depot resupply process provides the physical and informational linkages between the depot serviceable inventory of LRUs and the base-level serviceable inventory. The goal of this process is two-fold: first to satisfy the routine requisitions that arise out of the normal base-level requisitioning process described earlier; and second, to satisfy the high priority, mission capability (MICAP) requirements that arise when the routine system is unable to provide adequate numbers of LRUs to support the base-level flying program. The depot resupply process sector then includes the determination of MICAP requirements and the response to both MICAP and routine requirements.

Causal-Loop Diagram

Figure 3-25 is the causal-loop diagram for the depot resupply process. For clarity, certain elements of the routine

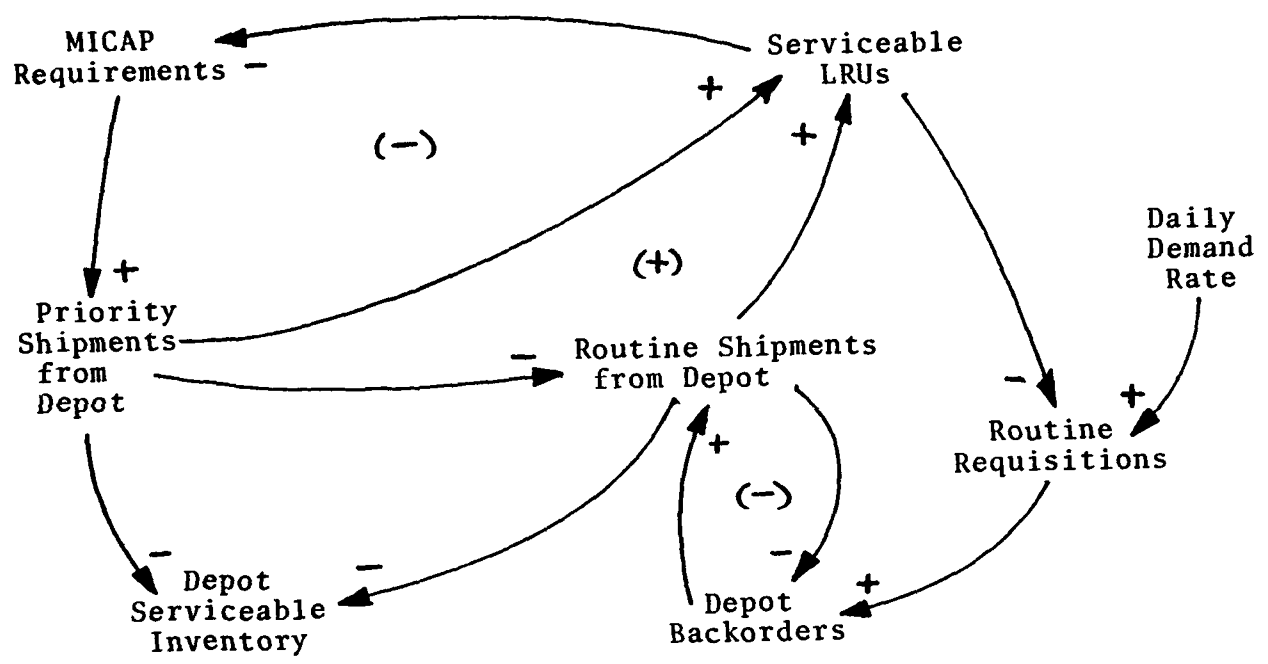


Figure 3-25

Causal-Loop Diagram of Depot Resupply Process Sector

requisition process sector are included. Note that as the level of depot backorders responds to routine requisitions, the rate at which routine shipments are made to the base level increases or decreases as needed to keep depot backorders within acceptable limits. Routine shipments, in turn, decrease the level of depot serviceable inventory.

The routine shipments are intended to replenish the base level of serviceable LRUs in response to historic usage and repair patterns. Short surges in flying hour activity may cause shortfalls in the level of serviceable LRUs that cannot be made up with routine shipments or base level repair of LRUs. Whenever these sources of serviceable LRUs cannot match the LRU demand rate, the serviceable inventory decreases. At some point this decrease in the number of serviceable LRUs will begin to affect the operational capability of the flying unit. This situation is reflected when an aircraft is determined to be Not Mission Capable - Supply (NMCS). In order to restore the NMCS aircraft, a Mission Capability (MICAP) demand is placed on the depot. This MICAP requirement will be satisfied by priority shipment of a serviceable LRU from the depot serviceable inventory.

The causal-loop diagram clearly shows that both priority and routine shipments are made from and compete for the same depot serviceable inventory. Furthermore, as the negative linkage between priority shipments and routine shipments implies, there is a point at which priority shipments will suppress routine shipments. This reflects the fact that

the depot serviceable inventory is, in fact, segmented. In the simple terms of this model, priority requirements have claim on all of the depot inventory. Routine requirements may not be filled from certain sublevels of the depot serviceable inventory. The nature of this competition and suppression is taken up in more detail in the discussion of the flow diagram.

Flow Diagram and DYNAMO Equations

Figure 3-26 and Table 3-8 show the flow diagram for the depot resupply process sector. As noted above, the sector is divided into two parts: the determination of MICAP requirements and the determination of the priority and routine shipment rates. Since the DYNAMO equations follow directly from the discussion of the flow diagram, they will be included in this section.

As noted above, MICAP requirements result when routine resupply actions and base-level maintenance are unable to support the LRU demand rate. We may postulate, then, that there is some threshold level of serviceable inventory below which the base will not be able to generate sufficient serviceable aircraft to satisfy its flying hour program.

The notion of this limitation was included in the discussion of the realized aircraft utilization factor in the LRU demand rate generation sector. In that sector, the absolute utilization limit (AUL) was defined as the maximum number of flying hours per aircraft per week that could be generated

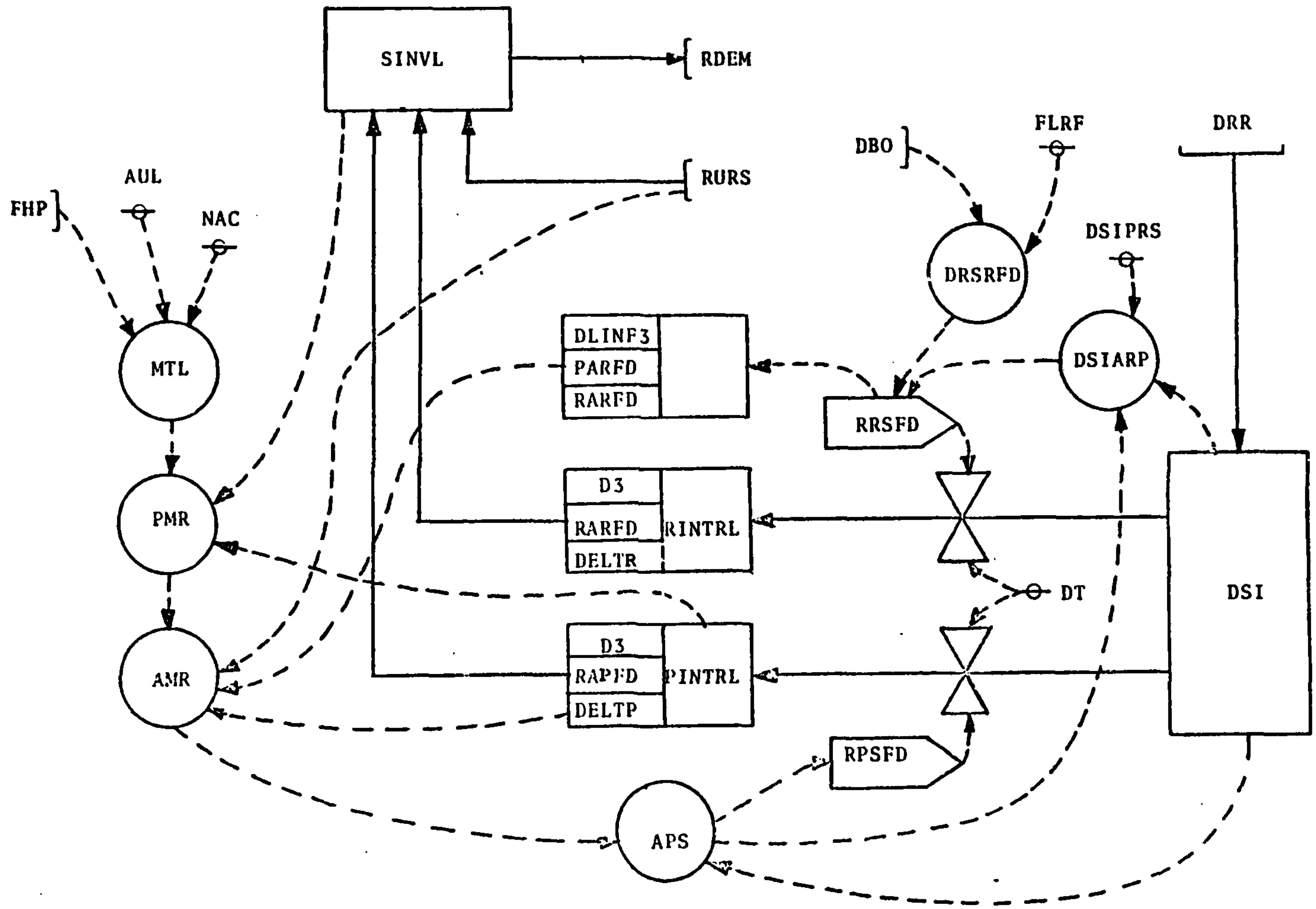


Figure 3-26

Flow Diagram for Depot Resupply Sector

TABLE 3-8

Variables Appearing in Figure 3-26

MTL	-	MICAP THRESHOLD LEVEL (LRUS)
FHP	-	FLYING HOUR PROGRAM (FLY HR/WK)
AUL	-	ABSOLUTE UTILIZATION LIMIT (FLY HR/AIRCRAFT/WK)
NAC	-	NUMBER OF AIRCRAFT (UNITS)
PMR	-	POTENTIAL MICAP REQUIREMENTS (LRUS)
SINVL	-	SERVICEABLE INVENTORY OF LRUS (LRUS)
PARFD	-	PERCEIVED ARRIVAL RATE ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
RRSFD	-	RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
RARPD	-	ROUTINE ARRIVAL RATE PERCEPTION DELAY (WKS)
AMR	-	ACTUAL MICAP REQUIREMENTS (LRUS)
RURS	-	RATE AT WHICH UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)
AMS	-	ACTUAL MICAP SHIPMENTS (LRUS)
DSI	-	DEPOT SERVICEABLE INVENTORY (LRUS)
RPSFD	-	RATE OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
PINTRL	-	PRIORITY SHIPMENTS INTRANSIT LEVEL (LRUS)
RAPFD	-	RATE OF ARRIVAL OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
DELTP	-	PRIORITY TRANSPORTATION PIPELINE DELAY(WKS)
DSIARP	-	DEPOT SERVICEABLE INVENTORY AVAILABLE TO THE ROUTINE PIPELINE (LRUS)
DSIMRS	-	DEPOT SERVICEABLE INVENTORY MICAP RESERVE STOCK (LRUS)
DRSRFD	-	DESIRED ROUTINE SHIPMENT RATE FROM DEPOT (LRUS/WK)
DBO	-	DEPOT BACK ORDERS (ORDERS)
FLRF	-	FILL RATE FACTOR (WKS)
RINTRL	-	ROUTINE INTRANSIT PIPELINE LEVEL (LRUS)
RARFD	-	RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
DELTR	-	ROUTINE TRANSPORTATION DELAY (WKS)

under the best circumstances. It was further noted that, for the hypothetical weapon system in this model, the best utilization that would ever be achieved was 85 percent of AUL, and that as a consequence, above 70 percent of this AUL the constraints on the weapon system would prevent realization of the desired number of flying hours. Thus, 70 percent of AUL represents the limit above which the system will begin to drop missions because of limitations on the weapon system. In terms of serviceable aircraft, the minimum number required to meet any given flying hour program without dropping any missions is:

FHP (fly hr/wk)/0.7 x AUL(fly hr/ac/wk)

If there are fewer aircraft than this available to the flying unit, then those aircraft will have to be flown more than 70 percent of their AUL, which means that there will be some missions dropped. Since we have assumed that all aircraft will have the LRU in question installed if one is available, the MICAP threshold level (MTL) is defined as:

A MTL.K=MIN((FHP.K/0.7*AUL),NAC))

On the basis of the discussion so far, it follows that a potential MICAP requirement (PMR) exists whenever base serviceable inventory falls below the MICAP threshold level. Since only new shortages can truly qualify as a potential MICAP requirement, the amount of stock already in the priority transportation channel (PINTRL) is considered as a base asset. Failure to include this variable in the potential MICAP requirement determination would cause the model to over-respond to

MICAP requirements due to the delay in the priority transportation channel (DELTP). Because of this delay previously demanded priority shipments arrive at the base over a period of time. Therefore the PMR determination must take into account the priority in-transit quantity so that MICAP requirements are generated only for new deficiencies at the end of each solution interval. The equation is:

PMR.K=MAX((MTL.K-(PINTRL.K+SINVL.K)),0)

Using PINTRL in the equation implies perfect information is available to base-level managers about the quantity in the priority pipeline. This would be the case in general; MICAP is an exception situation and is, therefore, not subject to the delays experienced in the routine order cycle. For comparison to the other delays in the system, the delay between the submission of a MICAP request by base management, and the notification of the base that the request has been satisfied, is negligibly small.

Once a potential MICAP requirement is identified, base management must determine whether an actual MICAP requirement exists. This decision is based on estimates of the likelihood of receiving the required quantity from the base repair process and the routine pipeline in the time that a MICAP shipment would take to arrive from the depot (i.e., DELTP). This decision is represented by the actual MICAP requirement auxiliary equation:

A AMR.K=MAX((PMR.K-RURS.JK*DELTP-PARFD.K*DELTP),0)

The MAX macro prevents nonsensical negative values from occurring. This equation contains two significant assumptions concerning this decision. First, it uses the value of RURS from the previous solution interval (JK), implying that supply managers have near-perfect information concerning the output of the base maintenance shops. The use of the JK value in this case is considered valid on the grounds that management has control over the repair process and, hence, will make every endeavor to satisfy the potential MICAP requirement from the base repair process. Using the JK value of the rate approximates this behavior, since it implies that base management has perfect information as to the actual instantaneous repair rate. In effect, this is momentarily true while base management attempts to satisfy the potential MICAP requirement by expediting the repair process. The second assumption concerns the perceived arrival rate from depot of routine shipments represented by the auxiliary variable PARFD. This variable is derived from the actual routine shipment rate from the depot (RRSFD) by a third-order information delay:

A PARFD.K=DLINF3(RRSFD.JK,RARPD)

In general base management will not know at any moment exactly what shipments the depot has dispatched to the base and their ultimate arrival times. There are information delays between the base and the depot, and the uncertainties of routine shipment pipelines preclude reliable estimation of the exact arrival times for shipments due in from the depot.

Therefore, at any moment under dynamic conditions, base management must base its decisions on an estimate of the arrival rate of routine shipments from the depot. In practice, this estimate is likely to lag changes in the actual rate. The determination of actual MICAP requirements assumes this lag in the estimated arrival rate can be represented by a third-order information delay of appropriate duration.

Having determined the actual MICAP requirement, the base places a demand on the depot for this quantity. The depot will satisfy the requirement provided it has sufficient stock in DSI. If it has less than the required quantity, it will ship what stock it does have. Since in a single-base, single-depot situation, the depot has no valid grounds for withholding supply, this decision structure is represented by the actual MICAP shipment (AMS) auxiliary variable:

```
A  AMS.K=MIN(AMR.K,DSI.K)
```

The priority shipment rate from the depot (RPSFD) is given by:

```
R  RPSFD.KL=AMS.K/DT
```

Note that this equation assumes that the MICAP requirement will be inserted virtually instantaneously (over one solution interval) into the priority pipeline. In practice, there will be an order cycle delay which includes the processing of the MICAP requisition and the preparation of the shipment. These delays, and the others incurred while determining the actual MICAP requirement and transmitting the MICAP requisition to the depot, have been aggregated into the priority transit

delay (DELTP).

As noted earlier in this sector, MICAP requirements have priority for depot serviceable inventory over routine requisitions. Having derived the rate at which the priority requirements are met, the routine requisition response can now be addressed.

Two factors combine to determine the rate that routine shipments are sent from the depot. The first is the depot serviceable inventory available for the routine pipeline (DSIARP). This reflects the amount of inventory available to the routine pipeline after actual priority shipments (AMS) and the depot serviceable inventory priority reserve stock (DSIMRS) are taken into consideration. DSIMRS provides a safety level of stock that will only be used to satisfy priority requirements, and advances the concept that the depot serviceable inventory is partitioned to meet different urgencies of need. The equation is:

```
A  DSIARP.K=MAX((DSI.K-DSIMRS-AMS.K),0)
```

The MAX macro prevents unrealistic negative values of DSIARP. For the purposes of the model, a 10 percent safety stock requirement for the depot serviceable inventory (DSI) was assumed. Since DSI was established as 10 LRUs, DSIMRS = 1.

The second factor used to determine the rate of routine shipments from depot is the desired routine shipment rate from depot (DRSRFD). This desired rate is the rate at which shipments would have to be made so that the current

level of depot backorders (DBO) would be cleared within the time frame established by the fill-rate factor (FLRF). This fill-rate factor represents the standard time that the item manager has to process a requisition and make a shipment against it. This standard time is 3 days or approximately 0.4 weeks (27). The equations are:

```
A  DRSRFD.K=DBO.K/FLRF
C  FLRF=0.4  WEEKS
```

The desired routine shipment rate (DRSRFD) will be achieved if there is sufficient depot serviceable inventory available for the routine pipeline (DSIARP). If, however, DSIARP is less than DRSRFD, the routine shipment rate from the depot (RRSFD) will be set so that all available DSI is shipped over the next solution interval. The FIFGE macro achieves this:

```
R  RRSFD.KL=FIFGE(DSIARP.K/DT,DRSRFD.K,DRSRFD,K,
                  DSIARP.K/DT)
```

The only structures remaining to be explained are the transportation pipeline delays. These delays accept as their input the routine and priority shipment rates. The delay constants represent the average pipeline times for priority and routine shipments which were assumed to be somewhat shorter than the standard times established by regulation (27). The outputs of these delays are the routine and priority arrival rates of shipments from depot (RARFD and RAPFD, respectively).

The consolidated DYNAMO equations for this sector are found in Appendix C, line numbers 6-1 to 6-21. In summary, the depot resupply sector consists of two major components which, together, provide the physical and informational links to the depot and base-level serviceable LRU inventories. Priority requirements are computed based on the ability of the flying unit to meet its flying hour program without dropping any missions. These priority requirements are satisfied from the depot serviceable inventory. Any remaining depot serviceable inventory, less priority safety stock, is used to satisfy the backorders created by routine requisition processes. The priority and routine shipments flow down two separate pipelines, arriving eventually at the base level where they replenish the serviceable inventory.

Chapter Summary

This chapter has presented the system dynamics model developed to represent the Air Force reparable asset system. Following the systems science paradigm explained in Chapter 2, the reparable asset system was first conceptualized as consisting of seven major process sectors, each of which contained several sub-processes. These processes were described and the major cause-and-effect relationships in each sector were illustrated in a causal-loop diagram. The causal-loop diagram provided a structural model of each process sector which then served to guide further analysis and measurement of the elements of the reparable asset system, their attributes, and

relationships. The results of this analysis and measurement were expressed in two ways: first, as a flow diagram showing the structure of the system, and the impact of information about system variables on the decision processes of that system; and second, as a mathematical model describing the time-oriented behavior of the system variables. Finally, the mathematical model was translated into equations in the DYNAMO simulation language and run with the computer. Each sector was run individually at first with simple, controlled inputs, and the output was rigorously analyzed in order to verify that the programmed model performed as it was expected to. Corrections to formulations were made as needed. In a few cases, complete reformulation of segments of the process sectors was necessary when the computer runs revealed unrealistic behavior in the system model as compared to the real system. As process sectors were completed, they were put together, and again the verification process was used to insure that the model results made sense.

With the verified computer model at hand, a series of structured interviews (see Appendix D) were conducted with experienced logistics managers and instructors in order to provide external validation to the model as developed. Using the flow diagram to facilitate communication between researcher and subject, questions were focused not only on how the subject viewed an area of expertise, but also the system in general. Whenever possible, subjects were asked to provide estimates of parameter values or to validate the parameter

values already included. As a result of the validation interviews, further additions and changes were made to the model.

The results of the effort just described have been presented in this chapter. The next chapter will advance the evaluation of the model as a policy analysis tool through further experimentation with realistic input functions.

CHAPTER 4

EXPERIMENTATION

Introduction

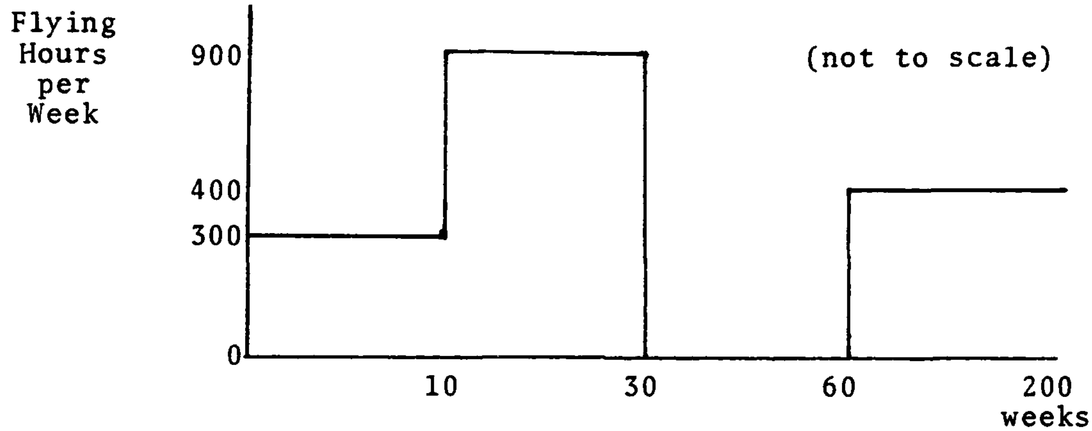
The previous chapter presented the model developed by this research. To evaluate the usefulness of this model as a policy analysis tool, two representative experimental runs of the model were made. This chapter presents the results of these runs of the model. The version of the model that includes the LRU and SRU base repair sector was used for these runs. The results demonstrate the types of output DYNAMO provides, and are indicative of the level of analysis which is possible with this type of model.

Selection of Experimental Runs

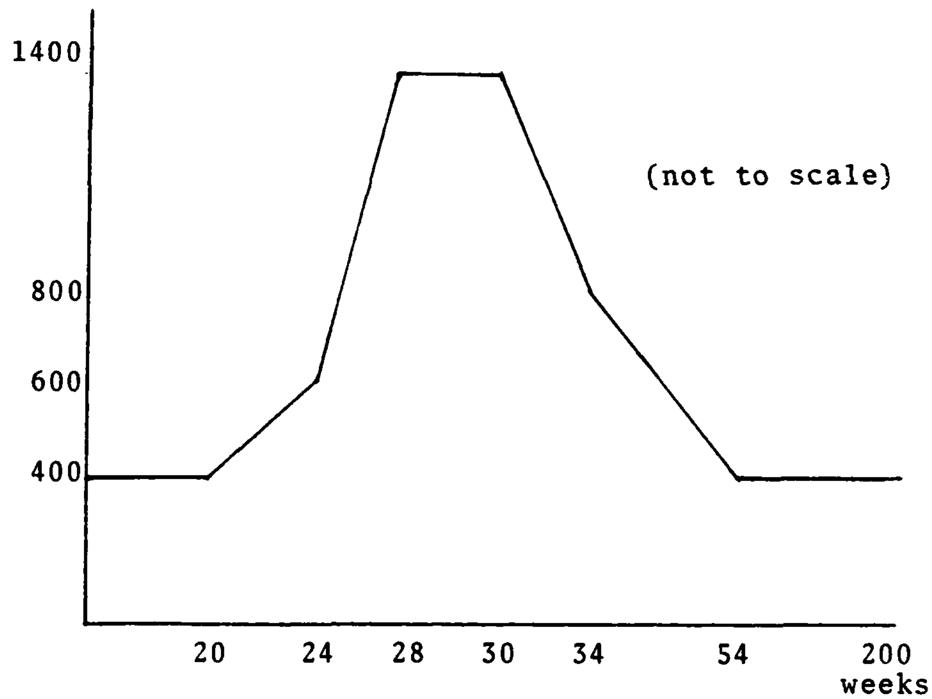
The model provides for a single exogenous input function, the flying hour program. This, however, does not imply that use of the model is restricted to analysis of the response of the system to various flying hour input functions. Any parameter in the model, or the structure of a part, or parts, of the model may be changed from one run of the model to the next. It is also possible to vary some parameters during the course of a run. Therefore, the experimental possibilities are virtually unlimited. The purposes of this report, however,

were best served by experimentation with different flying hour program input functions. The profiles for these functions are shown in Figure 4-1. Profile A is designed to exercise all aspects of model behavior. Profile B is a hypothetical profile which is representative of the type of short war scenarios employed in the current defense-related literature. Each profile will be discussed in more detail prior to the discussion of the results obtained with it. At this stage only the length of the runs requires further comment.

To illustrate the long-term implications of the system structure represented by the model, a run length of 200 weeks was selected. In practice, the model could also be used in this way to assess the long-term implication of proposed changes to the system. However, the real system is unlikely to remain unchanged over a period as long as 200 weeks. Therefore, whether or not the model's long-term results are useful will be heavily dependent upon the purposes for which the model is being used. If anticipated system changes are considered important, these changes will need to be incorporated. Depending on the nature of these changes, it may be possible to incorporate them into a single run of the model. If this is not possible, a number of shorter runs will need to be used. A single, long run suited the purposes of the experimentation in this research.



A. Test Flying Hour Program Input Function



B. Hypothetical Scenario Flying Hour Program Input Function

Figure 4-1

Experimental Flying Hour Program Input Functions

DYNAMO Output Options

To prepare the reader for the discussion of results which follows, a brief introduction to DYNAMO's output options is provided. DYNAMO provides two types of output: graphical and tabular. Each of these has its advantages. The graphical output displays the dynamic behavior of selected system variables as a function of time. By plotting several variables on the same graph, the model user is able to readily demonstrate dynamic interrelationships or detect the occurrence of events which warrant closer analysis. The tabular output facility of DYNAMO provides the means for this closer analysis.

DYNAMO will print in tabular format any variables the user designates. The user has complete control over the number of columns, the variables printed in each column and their order, the scaling of the output for each variable, and the time at which the values of the variables will be printed (to the nearest DT). This flexibility enables a more detailed level of analysis of significant events than that provided by the graphical output. The minimum time between the printing of tabular results is the solution interval for the model (DT). This level of resolution is particularly useful in the verification of the model equations.

Presentation of Results

Selected output from experimental runs with flying hour program functions A and B are included in Appendices E

and F respectively. Each appendix includes the graphical output for the full run length, but only a composite of the significant events from the tabular output. The graphical output for each run of the model is presented over a number of consecutive pages.

The significant entries in the tabular output are underlined and annotated with a reference number of parentheses to facilitate cross-referencing with the discussion of these results. The discussion of the results for each experimental run is preceded by a description of the flying hour program (FHP) input function used for that run.

Experimental Run 1 - Test FHP Function

Figure 4-1A presents the profile for the test FHP input function designed for experimental run number 1. The following DYNAMO equation provides this function:

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A  FHP.K=STEP(300,0)+STEP(600,10)-STEP(900,30)
                    +STEP(400,60)
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This function exercises all aspects of the model. The initial level of 300 hours per week for 10 weeks allows the model to achieve near equilibrium values for most rates and levels. The flying hour program (FHP) is then increased to a level which the system cannot sustain indefinitely. This level of FHP is maintained until the system has collapsed to a point where all attempts by the system to sustain this high rate of effort have been activated, and are operating at, or near, maximum capability; this occurs by about week 30. At this

point (week 30) the flying hour program is reduced to zero and held at that level until the system has virtually fully recovered and is near the point of zero activity (week 60). At this time FHP is set to a level which the system might be expected to sustain indefinitely.

Graphical Results for Test FHP Function

The graphical results for the test flying hour program input function are presented in Appendix E. The results show the behavior and interrelationships of ten of the more significant variables in the model (DYNAMO will plot up to ten variables per plot). The discussion of this output follows.

Time Zero to Week 10

This period was provided to allow the model to "start up." That is, to run from the initial values for levels and rates, set up by the N equations (refer to Appendix C), to near equilibrium values corresponding to the level of the flying hour program. The plots show that ten weeks was not long enough for equilibrium to be achieved. By week ten base serviceable stock (B) still exceeds the computed safety level quantity (Q). This indicates that the base routine requisitioning process is not yet active, and the base is allowing the NRTS rate to draw down its excess serviceable LRU stock to the safety level quantity level (SLQ). This section of the run was not extended to the equilibrium point because equilibrating behavior is also exhibited in the final section of the run.

Week 10 to Week 20

During this period the system is subjected to a very demanding flying hour program. This has a drastic effect on the system. The base workshop is unable to keep up with the high rate of demand for serviceable LRUs to support the demanded rate of effort. Consequently, base serviceable stock (B) is rapidly depleted. When base serviceable stock has been reduced to zero, the number of serviceable aircraft begins to fall off.

At about week 11, base serviceable stock has dropped below the SLQ level. At this time the base begins to place routine requisitions on the depot for serviceable units to fill base serviceable stock back to the SLQ level. As a consequence, the routine pipeline from the depot activates. However, because routine requisitions are a function of the daily demand rate (D), which is a highly smoothed measure of the actual demand rate (note how slow D is in responding the the step increase in F), the support provided by the depot (RARFD) is not sufficient to halt the decline in the number of serviceable aircraft (A).

Also of significance in this period is the steep decrease in the mean time between demands (M). This decrease begins at about the same time as the number of serviceable aircraft begins to decrease. Thus suggesting the decrease in M is due to the activation of the quality factors and is not simply a random downturn.

Week 20 to Week 23

During this period the trends established in the previous period continue. The daily demand rate (D) continues to increase as the smoothing process 'allows' D to recognize that a persistent increase in the actual demand rate has probably occurred. Q and R respond to this increase in D, but at much more gradual rates due to the smoothing inherent in the processes and delays which relate them to D.

The MTBD (M) continues to plunge during this period. Thus confirming that the action of the quality factors is masking the normal random variations. Recalling from Chapter 3 that the effects of lower quality output from the workshop (QF2) cannot have such an immediate impact of MTBD suggests that the rapid decrease in MTBD is due mainly to quality factor 1. In spite of the significant drop in the number of serviceable aircraft during this period, however, the wing is still able to achieve its assigned tasks.

Finally, this period shows a gradual increase in the level of URINV2 (the under repair inventory of LRUs awaiting the availability of serviceable SRUs). This indicates SRU availability is limiting the base workshop's serviceable LRU output rate and, thereby, increasing the deficit between the repair rate and the demand rate apparent in the previous period (note the increase in the slope of A after week 18 when the first, non-zero plot for URINV2 occurs).

Week 23 to Week 30

This period illustrates how much more responsive the

priority requisitioning (MICAP) system is than the routine requisitioning system in responding to a critical stockage situation at the base. At about week 23, the number of serviceable aircraft falls below the MICAP threshold level and MICAP requisitions are placed on the depot. This activates the priority shipments pipeline. As the priority shipments arrive at the base (RAPFD) the decrease in A stops, and A enters what can aptly be described as a MICAP plateau. Note that this is a consequence of the MICAP system responding to the whole of the actual requirement; whereas the routine system responds to a highly smoothed measure of the actual requirement. This plateau is short-lived, however; depot stock is rapidly depleted and, consequently, RAPFD drops off (when depot stock is depleted RAPFD is limited to the depot repair rate). At which time A resumes its previous rate of decrease. Note that as the depot responds to the MICAP requisitions and is unable to completely satisfy them, routine requisitions are no longer filled. Hence RARFD drops to zero.

Also of interest in this period are: the continual increase in URINV2, which indicates that SRU availability is limiting the serviceable LRU production rate to less than the design capability of the LRU base repair process; the leveling off of MTBD, which suggests the impact of the quality factors has run its course; and, after week 26 the wing is no longer able to achieve its assigned tasks (ROE is less than FHP). The rate of decrease in A suggests the relatively small deficit in this period would grow rapidly if FHP were to remain at 900

for much longer.

Week 30 to Week 40

During this period the system begins to recover from the surge of the previous period. Note the immediate jump in MTBD as the pressure on on-aircraft maintenance is removed. The effects of low quality output from the workshop, however, are not as quickly removed as is evidenced by the gradual increasing trend in MTBD over the period out to about week 80. The remaining variables behave as would be expected.

In the absence of MICAP requirements, depot stock begins to increase and when it exceeds the MICAP reserve level (note that R is zero until week 32), the routine backorders accumulated during the critical support period are progressively filled. Note that RARFD levels off at about the same value as RAPFD had dropped to just before week 30. This suggests RARFD is now being limited by the depot repair rate. URINV2 continues to increase for a short period as a consequence of the workshop attempting to shorten the recovery time by maintaining a high work rate for a period after the end of the surge.

As would be expected, the computed daily demand rate D is again slow to respond to the change in the actual demand rate (which is now zero). However, this has a beneficial effect in this instance as it keeps SLQ high. Consequently, the backorder pressure of routine requisitions is maintained on the depot and, as a consequence of this pressure, the depot provides maximum support to the base's recovery efforts.

Week 40 to Week 60

During this period the system recovers completely. The backlog of LRUs awaiting SRUs (URINV2) is eliminated (about week 48). The full complement of serviceable aircraft is re-established (note that this is indicated not only by trace A, but also by trace B since B indicates all serviceable LRUs in excess of those installed). Finally, the daily demand rate (D) eventually reaches the actual demand rate (note that this occurs 180 days after FHP is reduced to zero, as would be expected).

Trace B demonstrates the most significant behavior in this period. Trace B shows that the base routine requisitions decision structure leads to a large serviceable stock holding overshoot. By week 60 the computed safety level quantity (Q) is zero, whereas base serviceable stock (B) is approximately 15 and apparently still increasing. The reason for this overshoot is not evident from the plot. It is evident, however, from an examination of the routine requisitions decision structure represented in the model. This decision structure uses the NRTS rate to redistribute excess serviceable stock from the base to the depot (recall the discussion of the decline in B during the initial period). This releveling process is, however, inherently slow due to the disparity between the base repair rate and the NRTS rate. To understand the implications of this disparity one must look back at the response of the MICAP process during the surge. During the surge the MICAP process transferred all of the depot reserve stock to the

base. Therefore, at the end of the surge all stock except pipeline stock is at the base level. After the surge, when conditions are back to normal, such a high level of stock is not warranted. The large difference between the base repair rate and the NRTS rate, however, leads to serviceable stock increasing faster than the NRTS rate is able to redistribute stock to the depot. Hence, the overshoot evident in the plot.

Week 60 to Week 90

This period shows the rate at which the system is able to re-establish normal operating levels. The computed daily demand rate gradually recognizes the persistent change in the flying hour program, and reaches the true demand rate by about week 86. This response time corresponds closely with the 180-day smoothing built into the calculation. By about week 70, MTBD appears to recover fully from the decrease caused by the high work rate during the surge. After week 60 the NRTS rate releveling process steadily decreases base serviceable stock (B) to very near the safety level quantity by week 90. The sharp initial decline in B is probably due to the initial delay by maintenance management in responding to the sharp increase in flying rate.

Week 90 to Week 200

During this period the system appears to achieve equilibrium. Base serviceable stock drops to below the safety level quantity and the routine requisitioning and resupply process reactivates. Fluctuations are due to variations in

the actual demand rate, due to fluctuations in the apparent MTBD (M). Noteworthy is the inability of the routine requisitioning system to maintain (or even achieve) the safety level quantity. Most significant, however, is that the system is only apparently in equilibrium. All the plotted quantities, except URINV2, if observed in isolation, or compared to each other, suggest the system is in equilibrium because all fluctuations apparently are due to MTBD fluctuations and the base is sustaining the assigned flying hour program. URINV2, however, is steadily increasing. This indicates base maintenance is not able to repair LRUs at the desired rate due to a shortfall in the availability of serviceable SRUs. This suggests the SRU repair process will eventually limit the base's ability to meet the FHP. *Therefore, although the system appears* to be in equilibrium, and able to sustain an FHP of 400 hours per week indefinitely, the system is actually slowly collapsing.

The implications of this collapse trend for the real system are significant. The model depicts the interaction of average values and, therefore, the collapse trend is readily apparent. Managers, however, must contend with the real-time fluctuations of the system's rates and levels, and may not be aware of a gradual change in the average values until a significant shift has occurred. This perception lag may lead to the setting of optimistic planning factors for the system. For example, it may cause good management indicators to be overlooked; and it may cause the effectiveness of certain policies to be assessed too optimistically.

The following section discusses the tabular results for the test flying hour program input function.

Tabular Results for Test FHP Function

The graphical results provide an excellent means of displaying the dynamic interrelationships of system variables, but are limited in their ability to resolve small differences between variables. Side-by-side comparison of variables is also limited, unless the user is prepared to manipulate a number of plots. The tabular results complement the graphical results by providing the means for more detailed analysis and the simultaneous, point-in-time comparison of many variables. The following discussion is indicative of the level of analysis the tabular results permit. The discussion refers to the tabular output in Appendix E.

Time Zero

This block lists the initial values established by the N equations (refer to Appendix C). Of signficance is the low initial value for the safety level quantity (SLQ) in comparison to the initial level of base serviceable stock (BSS) (1), and the low MICAP threshold level (MTL) (2) due to the combination of the high number of serviceable aircraft with the relatively low FHP.

Week 1

The tabulated values in this block are the values at the end of week one, when TIME is equal to 1.00. The model

has run for a simulated one-week period. Of significance at this time is the relatively high values of repair rate factor 3 (RRF3) (1) and the SRU repair rate factor (SRURRF) (2) in comparison with the values for RRF1 and RRF2, and the discrepancy between the actual rate of demand (RDEM) and the rate unserviceable units undergo repair (RUSUR) (3).

The high value for RRF3 represents the pressure to avoid any build-up in the awaiting SRUs inventory and results in a desired LRU repair rate which is higher than the actual LRU diagnosis rate. Hence, the LRU repair rate is limited to that which will just reduce URINV2 to zero at the end of each DT. The LRU repair rate is equal to the diagnosis rate representing concurrent diagnosis and repair in the real system.

The difference between the actual demand rate and the workshop input rate (RUSUR) shows the effect of the management perception delay in assessing the actual rate of demand. Because of this delay, a slight-build-up is occurring in unserviceable inventory (4). This build-up peaks during week two.

<u>Week 2</u>

By this time, maintenance management has recognized that a change in the rate of demand has occurred and, therefore, has set the work rate such that the demand rate can be sustained and the backlog of USINVL is gradually reduced.

RUSUR is now greater than RDEM due to the demand rate pressure factor RRF1. But note that RRF1 is still increasing (look ahead to week 4). This can be interpreted as an over-

response by management due to the desire to prevent a backlog in USINVL, and the uncertainties in estimating the actual rate of demand. It could also indicate that the response of RRF1 in the model should perhaps be more gradual at this level of demand. Research into the specific form of the RRF1 function for a given application would provide more accuracy here, but the behavior indicated by the present values is unlikely to change.

Week 4

By this time, maintenance has overcome the backlog in USINVL due to their initial lag in responding to the step increase in the rate of demand at time zero. The work rate, therefore, (RUSUR) is now equal to the rate of demand (RDEM). RRF1, however, is still increasing slightly. This represents the fact that management is still uncertain about the actual rate of demand. It also reflects the capacity of the system to respond to steeper changes in the actual rate of demand.

Week 9

At this point in the run RUSUR is virtually equal to the rate of demand (1) even though RDEM is continuously changing as MTBD changes. This shows that the delay in management's perception of a change in RDEM has negligible effect when RDEM changes gradually.

The depot serviceable inventory (2) is increasing gradually as a result of the NRTS rate releveling process. Base serviceable inventory has dropped by about 3.5 units.

Approximately two of these are at the depot either in the transportation and repair process or in serviceable stock. The remainder have been absorbed as the base repair cycle quantity.

The base stock of spare SRUs (BSSRUI) is decreasing gradually (4). However, at this stage the SRU process is keeping pace with the changes in RSRUR. The observed decrease is due to the initial drop as the SRU repair processes and depot pipeline are filled up, and subsequently due to the response delay between changes in the LRU diagnosis rate (which generates the reparable SRUs) and the SRU repair rates.

<u>Week 10</u>

At this point an instantaneous step to 900 hours per week occurs in the flying hour program. This results in a number of significant events. The demand rate (RDEM) increases accordingly and, in fact, exceeds the maximum throughput capacity (MAXTP) of the LRU repair process (1). The high FHP significantly increases the pressure on flight-line maintenance to sustain a relatively high average aircraft utilization (RAU). Hence a tendency to speed up aircraft turnaround by replacing a number of LRUs to correct a fault rather than tracing the fault to a particular LRU is becoming apparent (QF1 is less than 1.000 (2)). The system is attempting to trade off lower on-aircraft maintenance time for a higher workshop workload.

The managerial perception delay has prevented RUSUR from responding at all to the large instantaneous change in

the average demand rate which occurs at this time (3). In practice, it is impossible to measure instantaneous rates. Therefore the complete lack of response by RUSUR accurately represents this real-world constraint. Looking ahead, however, shows that RUSUR reaches MAXTP by week 12, thus indicating that in spite of the managerial perception delay, maintenance management will quickly increase to maximum effort if the change in the perceived demand rate is relatively large. Finally, as a consequence of the increased flying program commitment, a corresponding increase in the MICAP threshold has occurred (4).

Week 11

By this time the increase in the LRU demand rate has led to an increase in the LRU diagnosis rate and, hence, the rate at which reparable SRUs are generated. In fact, RSRUR is now higher than the maximum throughput capability of the SRU repair process and, consequently, the rate at which SRUs undergo repair is at its maximum (1).

From this point then, a rapid depletion of base serviceable SRU inventory (BSSRUI) can be anticipated. Also of interest at this time is that the high rate of demand during week 10 has depleted base serviceable stock to a point below SLQ (2). The base routine ordering process has responded by raising requisitions for depot resupply, but although the depot has responded to some of these requisitions (3), the shipments have not yet left the depot (4).

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Week 12

At this time, the perceived demand rate pressure factor (RRF1) has reached maximum (1). Although RRF1 did not instantly respond to the increase in FHP at week 10 as did the inventory (anticipated requirements) pressure factor RRF2 (RRF2 is greater than RRF1 at week 10), RRF1 is first to reach maximum. As a consequence, RUSUR is maximum and, although the effect is negligible at this time, the workshop quality factor is responding to the high work rate (2).

The shortfall in workshop production capability is causing a build-up in the work backlog in USINVL (3). Note, however, that no backlog is apparent in URINV2 at this time since the initial stock of serviceable SRUs (BSRU) has not been depleted to the point at which SRU availability becomes the limiting factor on the LRU repair rate.

Finally, note that although base serviceable stock is now zero, the base is continuing to raise routine requisitions as a consequence of the steady increase in the safety level quantity. As was indicated in the discussion of the graphical results, this steady increase is due to the slow response of the daily demand rate to the change in FHP.

Week 13

By this time, routine shipments from the depot have reduced depot stock to below the initial stock level. As a consequence, pressure from the requirements determination process begins to reduce the depot delay factor (1). This causes

the depot repair rate to increase. Thus the depot repair rate at week 13 is equal to the input rate to the depot (NRTS rate) a little earlier than if DRD had not decreased. However, as these rates were very nearly equal prior to the decrease in depot delay (see week 12), the impact on the system is negligible. Although insignificant in terms of system performance, this change in the depot delay can be interpreted as an indication that the item manager is aware of an apparent abnormally high demand rate which warrants closer monitoring but no corrective action at this stage.

The final point of interest is that because the base still has a relatively good supply of serviceable SRUs, the workshop is repairing LRUs at the maximum possible rate (LRUDR= LRURR=(1-PROPD)*MAXTP=1.6000). The SRU consumption rate, therefore, is also at maximum (2). This is a significant observation.

The results show that the maximum consumption rate for SRUs is 4 per week. From this, it follows that the maximum rate reparable SRUs can be generated is also 4 per week; since in the limit, the maximum LRU repair rate is limited to the maximum LRU diagnosis rate. In the model, however, the maximum throughput rate for the SRU process is set at 3 per week; 1 per week less than the maximum rate the LRU process demands. This explains the steady increase in URINV2 observed in the graphical results. More important though are the implications of this observation for system design and the further development of the model.

With respect to system design, the model suggests that SRU availability will not be a problem, on the average, if the maximum throughput of the SRU repair process is at least equal to the reparable SRU generation rate corresponding to the maximum LRU diagnosis rate (LRUDR(max)*SRUGF). The implications for further development of the model are perhaps more important.

If the actual maximum SRU throughput (MTPSRU) is equal to or greater than the maximum LRU diagnosis rate times the SRU generation factor, SRU availability will only temporarily limit the LRU repair rate when the LRU diagnosis rate increases suddenly and, prior to the increase, the availability of SRUs was just sufficient to support the desired LRU repair rate. How long the LRU rate will be limited will depend on the delay factors for the base and depot SRU repair processes. In view of this relatively short-term interaction, further elaboration of the representation of the SRU process does not seem warranted. The basis of this conclusion, however, is the SRU generation factor. It is possible that this factor is too simple a representation of the actual process by which reparable SRUs are generated and, subsequently, consumed by the LRU process. Therefore, before the present simplified representation of the SRU process can be accepted as adequate, further research into the LRU/SRU interface is indicated.

Week 18

Significant at this time is the level of USINVL and the LRU repair rate. The backlog in USINVL (1) now exceeds

13.5 (MBBLOG) and, hence, the diversion to depot process is active. Due to the high demand rate the diversion to depot rate (DTDR) is already at maximum, as is indicated by the total rate to depot (TRTD) being at its maximum of 0.8 per week.

The LRU repair rate is now less than the maximum possible (2), which was achieved at week 13 and maintained until week 17 due to the depletion of the base's initial stock of serviceable SRUs.

Week 24

At this time, the depot stock level (DSI) has dropped off to about 50 percent of its initial value. The requirements determination process has recognized the decreasing stock position, however, and adjusted the depot repair delay accordingly (1). Of particular interest is the fact that as a consequence of the reduction in depot repair delay (RDR), the depot repair rate (DRR) now exceeds the input rate to the depot (TRTD). This result closely represents system behavior under these circumstances. The reduction in depot repair delay (DRD) represents the item manager's ability to expedite the repair of LRUs by his technology repair centers (TRCs) and contractors. The increase in the depot repair rate represents the initial surge in output which results when repair is expedited, because the units in repair, at the time repair is expedited, become available sooner. As these expedited, under repair units leave the repair process, however, the repair rate returns to the level of the input rate. Except that now, due to expedite

actions, the average time units spend under repair is lower. In the model this condition is achieved at week 32, which is six weeks after the depot repair delay (DRD) reaches its minimum value.

Week 24 also shows the first potential MICAP requirement (2), thus indicating that the number of serviceable aircraft is now at a critical level. At this stage, however, the base is not justified in raising a MICAP requisition (3). Nevertheless, a slight rate of effort shortfall has resulted (4), in spite of maximum pressure being exerted on the workshop to support flying hour and aircraft utilization requirements (5). Obviously this pressure cannot have an effect on the workshop production rate since the workshop is already at MAXTP. However, the pressure does exist in reality. It represents the fact that the base will take all possible means to avoid raising a MICAP requisition, and insures that the workshop works at maximum capability as long as a potential MICAP situation exists. Note that as a consequence of decreases in the rate of effort, due to aircraft utilization limitations, the demand rate pressure will decrease accordingly. Eventually a situation will arise in which the low demand pressure (RRF1) would allow the workshop to slow down, were it not for repair rate factor two's (RRF2) continued recognition of the shortfall between the demanded rate of effort (FHP) and the actual rate of effort (ROE).

Week 27

At this time, depot stocks have dropped to the point where routine requisitions are no longer being filled (DSIARP=0 and RRSFD=0). This critical stock position is also indicated by the depot repair delay being at its minimum value.

Week 28

MICAP shipments over the past four weeks have now reduced depot stocks to the point that the depot is no longer able to fill MICAP requisitions as they are received (AMS is now less than AMR). As a consequence, the number of serviceable aircraft is now decreasing again (the end of the MICAP plateau occurred during week 27).

The MICAP plateau began during week 25. Therefore, the MICAP resupply process was able to arrest the decline in serviceable aircraft for about two weeks. If the demanded rate of effort had been higher, MICAP requirements would have occurred earlier and the MICAP plateau would have been shorter. Thus the model provides a means of determining the degree of support provided by a certain stockage policy or the depth stock required for a specified level of support.

Week 29

Week 29 is the last printout point before FHP is reduced to zero at week 30. Of interest here is that although the achieved rate of effort (ROE) is less than the flying hour program and has been so since week 25, the aircraft utilization has not yet achieved the maximum practical limit of 21.25 hours

per aircraft per week. This indicates that the present shortfall is not sufficient to cause management to take all possible measures to meet the demanded rate of effort. This reflects reality in that it means that a significant shortfall in the achieved rate of effort is required before management will feel compelled to take all possible extracrdinary measures to maximize the realized aircraft utilization.

Week 30

At this point, FHP is suddenly reduced to zero (1). Therefore, the MICAP threshold is zero and, consequently, priority shipments from the depot cease (2). Base maintenance, however, maintains its rate of work at maximum (3). This reflects the practice of maintaining a high maintenance work rate for a period immediately after a surge in operations in order to take advantage of the lull in flying operations to reduce the work backlog somewhat before normal operations start up again. In fact, the model parameter set shows maintenance does not drop its work rate to minimum until week 35.

Week 31

This block shows the depot is still not filling routine backorders (1) even though depot stock is now increasing (2). The reason for this is that the item manager is reestablishing the MICAP reserve stock before satisfying routine backorders (DSIARP is zero at this time (3)).

Week 32

By this time, depot stock has increased to above the MICAP reserve level (1), and routine requisitions are being filled as soon as stock is available. Note, however, that the routine fill rate is less than desired (2). The fill rate is in fact being limited by the depot repair rate, as was the MICAP fill rate just prior to the reduction in FHP. This shows that the routine pipeline provides the same degree of support to the base in these circumstances as does the priority pipeline. The only difference between the two being the higher pipeline quantity incurred through the use of routine transportation.

Week 33

During this week the minimum value for quality factor two (QF2) occurs (1). This is some 30 weeks after it first responded to the high work rate in the workshop. On the other hand, QF1 was quick to respond initially when FHP increased at week 10, and quick to reset to 1.000 again at week 30 when FHP dropped to zero. These results contrast the different degrees of responsiveness of the determinants of quality embodied in the two factors,QF1 and QF2.

The peak value for URINV2 also occurs during this week (2). Note that since week 30 USINVL has decreased steadily, but URINV2 has continued to increase due to the high work rate being maintained by the workshop. However, by this time the LRU diagnosis rate is only just above the maximum the SRU

process can sustain (1.200), and is gradually decreasing (by week 34 it is less than 1.2000). Therefore, during week 33 the LRU diagnosis rate drops below 1.2000. The LRU repair rate, however, remains at 1.200 due to the action of RRF3 and the constraint of SRU availability. Consequently, URINV2 begins to decrease during week 33.

Week 36

By week 36 the maintenance rate of effort has dropped to the minimum level (1). Even at this level, however, maintenance is still unable to repair LRUs at the desired rate (2) due to limited SRU availability. Note that although the LRU process has slowed to minimum throughput, the SRU process is being maintained at maximum throughput since the desired LRU repair rate is not being achieved (3).

Also of significance at this time is steady recovery of quality factor two (QF2). The steady increase in QF2 reflects the improvement in overall MTBD due to the flow of normal quality LRUs into SINVL, which began at about week 32, when the maintenance work rate began to decrease to normal levels. Note that in the model QF2 would eventually fully recover if FHP remained zero long enough. This would indicate that none, or negligibly few, low MTBD LRUs were in the serviceable LRU inventory (SINVL). In practice, this would not be the case. While FHP remained at zero, the demand rate would also be zero, or very nearly zero (there may be some demands due to on-aircraft maintenance activities). Therefore,

most of the low MTBD LRUs which entered SINVL during the period of high activity would remain in SINVL until flying recommenced. In reality then, MTBD would not fully recover to its normal level. On the other hand, in practice FHP is unlikely to be zero for extended periods and, under these circumstances, the response of QF2 would be more realistic.

Week 43

By this time, the base work backlog in USINVL has been reduced to the point that extraordinary depot support is no longer warranted (1). Hence the diversion to depot rate is now zero (2). Note, however, that this reduction in the flow of reparables to the depot will lead to a reduction in the depot repair rate. This, in turn, will lead to a drop in the depot's fill rate for routine requisitions since at this time the depot fill rate is still less than desired (3).

Week 46

By week 46 base serviceable stock has recovered to the point that is now exceeds SLQ (1). Therefore, no more routine requisitions are raised. However, approximately 13 LRUs are still either under repair, or awaiting repair at the base (2). Most of these will end up in SINVL due to high percentage of base repair for these LRUs (2). Hence, the build-up of excess base serviceable stock shown in the graph results.

Week 60

At this time the system is virtually at a standstill, only the SRU process is still active at the base. At the

depot SRU repair is still active; LRU repair has almost wound down; and, due to the lead times involved, reacquisition is still active. The flying hour program increases to 400 hours per week at this point.

Week 76

By this time the stock of serviceable SRUs built up during the period of no flying has been depleted and the limited SRU repair capacity is once again limiting the LRU repair rate (1). Note that except for the SRU process, the wing would be able to support a flying hour program of 400 hours indefinitely (RUSUR is equal to RDEM) (2).

Week 87

At this time depot serviceable stock has recovered to its initial value for the run (1). Note, however, that this is not the appropriate level for the current demand rate as the base serviceable stock still exceeds SLQ (2).

Week 92

Base serviceable stock finally has dropped to below SLQ and the routine resupply process is once again active (1) Note that except for the effects of the SRU process, the base is apparently meeting its commitments without difficulty.

Week 200

At this time the system is still managing to keep base serviceable stocks near the SLQ level, and is sustaining the flying hour program. Note, however, that this has been made

possible by a steady transfer of stock from depot serviceable inventory into URINV2, and it will not be long before the number of serviceable aircraft begins to decrease. Moreover, the results show that the system will not be able to sustain 400 flying hours per week.

To see why the system will not sustain 400 hours per week, consider the system behavior this run has demonstrated. First, the LRU repair rate is limited by the SRU process to 1.2 per week. Second, recall that as the number of serviceable aircraft declines, this will eventually cause the workshop to work at the rate dictated by the demand rate (RRF2 pressure overcomes the perception lag inherent in demand pressure). At the same time, backorder pressure will maintain the depot requisitions fill rate at the maximum permitted by the depot repair rate. The net effect of these actions will be to maintain the SINVL fill rate very near the demand rate, except for periods when the demand rate exceeds the capability of the system. The system parameters suggest that this capability is 1.5 LRUs per week. This figure is obtained by the following reasoning.

The base LRU repair rate is limited to 1.2 per week. Therefore, it remains for the depot to support demand in excess of this. But the depot resupply rate is limited by the NRTS rate which, in turn, is determined by the base repair rate which, under these circumstances, is equal to the demand rate as long as the demand rate is no more than two per week. Recognizing this, the point at which the demand rate will

exceed the SINVL fill rate can be determined. Ignoring the depot response delays, i.e., the depot fill rate contribution to SINVL is equal to the NRTS rate, it is possible to compute the demand rate above which the NRTS rate and the LRU repair rate can no longer maintain the level of SINVL. This rate of demand is 1.5 per week (1.2 per week plus 1.5*0.2 = .3 per week).

Recognizing now, that the average demand rate for a rate of effort of 400 hours per week is 1.6 per week (400/250) shows the system will not be able to sustain the demanded rate of effort.

It should be apparent that while the foregoing calculations are possible without reference to the model results, the model provides the solutions much more readily. Moreover, the model also provides the time behavior of the system not only in response to the current FHP, but also to changes in FHP and any other parameters in the system at any time.

This concludes the analysis of the system behavior corresponding to the test flying hour program input function. The next section of this chapter discusses the results obtained from the model with the hypothetical wartime flying hour scenario (Figure 4-1B).

Experimental Run 2 - Hypothetical Scenario

Description of Flying Hour Program Function

Figure 4-1B shows the profile of the flying hour program (FHP) function designed for experimental run two. The

following DYNAMO equation provides this function:

```
A   FHP.K=400+RAMP(50,20)+RAMP(150,24)-RAMP(200,28)
              -RAMP(150,30)+RAMP(130,34)+RAMP(20,54)
```

The function represents the following hypothetical short war scenario. The initial period of 20 weeks allows the model to start up. The flying hour program of 400 hours per week for this period is representative of normal peace-time training activities (12:11). The four weeks from week 20 represent the gradual increase in operations which normally precedes the declaration of war. The scenario assumes that war is declared at week 24. The four weeks following the declaration of war shows a steep increase in the flying hour program, which reflects the normally rapid escalation of war operations. Following this period is a two-week plateau at maximum effort. In reality this plateau may be longer or shorter, depending upon how strong the enemy is. The decline in operations from week 30 to week 34 represents the relatively sharp drop off in air operations, which would occur as the tide of battle turns in favor of the allies. The gradual tapering off of operations as the war draws to an end is represented by the decline in the flying hour program from week 34 to week 54. After week 54, operations return to peace-time levels (no low activity recovery period is included in order to test the implications of such a policy).

The flying hour function just described represents a thirty-week war which is preceded by a short period of

increasing tensions. The purpose of the experiment is to test the ability of the reparable asset system to respond to and sustain the demands of war without major changes in policy or availability of resources. Considering the popular opinion, expressed in the current defense literature, seems to be that future wars will be too short for major reacquisition and, therefore, will be fought with the resources on hand at the beginning. This experiment seemed particularly pertinent.

Graphical Results - Hypothetical Scenario FHP

The graphical results for the hypothetical scenario flying hour program input function are in Appendix F. The discussion of these results follows the same format as was used for the previous experiment.

Time Zero to Week 20

This is the start up period. The main concern here is to allow the system to reach equilibrium before the scenario profile begins. The results show the system equilibrates at about week 17. That is, base serviceable stock has leveled off at a value less than the safety level quantity, and the corresponding rate of arrival of routine shipments from the depot has also stabilized.

Week 20 to 24

During this period the pre-hostilities build-up in operational activities occur. The resulting increase in the demand rate causes a steady increase in base serviceable stock,

and the depot routine resupply process responds (RARFD). Depot support, however, is obviously not adequate as it has no apparent effect on the rate of decrease of base serviceable stock. The reason for this lack of support can be seen in the lack of response of the computed daily demand rate (D) to the increase in the actual demand rate during this period.

<u>Week 24 to 28</u>

This period shows the rapid escalation of flying operations in the early phase of the war. Of particular significance in this period is the sharp decrease in MTBD from week 25 (one week into the escalation period). As discussed for the previous experiment, this is almost entirely due to the response of on-aircraft maintenance quality (QF1) to the increased aircraft utilization pressure.

At week 25 base serviceable stock is depleted and the number of serviceable aircraft begins to fall. At about the same time the base stock of spare SRUs is also depleted, as is evidenced by the first non-zero plot for URINV2 at week 26.

The computed demand rate is responding gradually to the increasing actual demand rate. Consequently, the safety level quality (Q) and, hence, the routine resupply rate (R) are also increasing. These increases, however, are not able to prevent the decrease in the number of serviceable aircraft. By week 28 the base is unable to meet all of its assigned tasks (ROE is less than FHP).

During week 27 the base enters a continual MICAP

condition. The depot responds strongly to this with priority resupply, and the number of serviceable aircraft stops decreasing and enters the MICAP plateau.

Week 28 to 30

During this period the flying hour program is at maximum and constant. The base, however, is not able to achieve the demanded program in spite of priority depot support. In fact, the priority depot support is short-lived. Due to the high demand rate, depot reserve stock is quickly depleted and by week 29, the number of serviceable aircraft is decreasing again. (The reason the number of serviceable aircraft (A) shows a slight increase at the end of the MICAP plateau is discussed in the tabular results for week 28.)

The decline in the rate of arrival of routine shipments from the depot after week 28 highlights the rapidity with which the MICAP response has depleted depot stocks. Since it shows that the MICAP response almost immediately causes routine shipments to be stopped, a not unexpected occurrence under the circumstances. At the end of the period the priority resupply rate has dropped significantly. This indicates depot stocks are exhausted and LRUs are being shipped to the base as soon as they are available after repair.

Week 30 to 34

During this period the intensity of operations drops off sharply. Consequently, the achieved rate of effort (E) and the demanded rate of effort (F) apparently are equal again

by week 32. Closer analysis, however, suggests there is still a slight shortfall at the end of the period which the plot scale is unable to resolve. This shortfall is indicated by the priority pipeline (P) still being active at week 33 (the tabular results show a shortfall in rate of effort into week 32).

This period shows that the decrease in on-aircraft maintenance quality due to pressure to increase aircraft utilization has its full effect on MTBD by about week 31.

Finally this period highlights the poor responsiveness of the daily demand rate computation. The computed demand rate is still increasing in response to the prior surge when, in fact, the actual demand rate is decreasing. Looking ahead reveals that the computed demand finally peaks at week 50. At this time, however, the actual demand rate is almost back down to prewar levels.

Week 34 to 54

This phase of the scenario sees a gradual reduction in the intensity of operations to eventually reach peacetime levels by the end of the period. During this period the number of serviceable aircraft continues to decline, but the base is able to meet the flying program.

Priority resupply is no longer necessary after about week 34. Therefore, after a short delay, while the depot reestablishes its MICAP reserve stock, routine resupply activates. However, as for the test FHP function, the depot backorder fill rate is limited by the depot repair rate. The arrival rate

of routine shipments, therefore, levels off at about .8 LRUs per week (the depot maximum throughput rate).

MTBD appears to continue to decrease over this period. This demonstrates the slow response of MTBD to the flow of low MTBD LRUs from the workshop which began at about week 22, the time at which the base workshop attains its maximum work rate.

Finally, the level of URINV2 increases steadily over this period, indicating that the decline in serviceable aircraft is being aggravated by a less than maximum LRU repair rate due to low SRU availability.

Week 54 to 200

This period represents a return to peacetime operations. The period was extended to 200 weeks to test if the system is able to fully recover and, if so, in what time scale. The results show the system is unable to recover fully. The number of serviceable aircraft stabilizes at approximately 40 at about week 105 (one year after the return to peacetime operations). The reason for such a poor recovery is apparently the inadequate capacity of the SRU repair process relative to the LRU process, as evidenced by the steady increase in URINV2.

From about week 60 to week 100 the MTBD steadily increases. Thus indicating that on-aircraft maintenance quality and the quality of repaired LRUs from the base workshop return to normal soon after the return to peacetime operations.

Of particular significance in this period is that this period shows the slow response of the computed demand rate

does not affect the rate at which the system recovers.

The computed demand rate peaks at week 50 (20 weeks after the actual peak in demand) and then drops back to the actual demand rate at about week 100. However, during this time the depot fill rate for routine requisitions is limited by the depot's repair rate capacity. Therefore, even though the computed safety level quantity (SLQ) is artificially high, the depot is not able to fill to this level before the SLQ drops to the actual level. Under the circumstances represented in this experiment, the depot is never able to achieve its desired fill rate and, therefore, the level of SLQ is immaterial. In fact, the depot's ability to fill routine requisitions is reduced at about week 110. At this point the depot resupply rate drops as a consequence of the deactivation of the diversion to depot process (DTDR).

This concludes the discussion of the graphical results. The discussion of the tabular results follows.

Tabular Results - Hypothetical Scenario FHP

The tabular results for the hypothetical scenario flying hour program input function are in Appendix F.

Time Zero

This block lists the initial conditions for the experiment. These initial conditions are the same as those used for experiment 1, except for the higher initial flying hour program and, as a consequence, the higher initial demand rate.

Week 1

By the end of week 1, the SRU repair process is already operating at maximum capability and is unable to keep up with the demand for SRUs (1). However, the initial stock of spare SRUs is able to make up the shortfall and sustain the desired LRU repair rate (2).

Week 13

By this time the NRTS rate leveling process has decreased base stock to the point that base serviceable stock is now less than the computed SLQ (1). Consequently, the base routine requisitioning process has been activated. Depot backorders, however, are still at zero (2), indicating the first routine requisitions are still being processed.

Week 19

Base serviceable stock shows an increase since week 18 (1). This indicates the system is now in equilibrium with respect to the distribution of stock between the base and the depot. At this time the base stock of serviceable SRUs is still supporting the desired LRU repair rate (2).

Week 21

At this time the flying hour program has increased by 50 hours per week (1). Base maintenance is responding to the increase in demand by increasing the rate unserviceable LRUs go under repair (RUSUR) (2). The supply of serviceable SRUs is still sustaining the desired LRU repair rate (3).

Week 23

The increasing rate of effort has, by this time, led to a demand rate in excess of the base repair process maximum throughput capability (MAXTP). Therefore, from this point onwards a progressive build-up of reparable LRUs at the base can be anticipated.

Week 25

As a consequence of the sharply increasing rate of effort, a number of significant events are apparent at this point in the scenario. In response to the steep increase in demand pressure the base repair process is operating at maximum capability (1). As a consequence of the extraordinary work rate, the quality of output decreases. This will gradually decrease the MTBD of the inventory of serviceable LRUs (2). The demand for higher aircraft utilization is also beginning to affect MTBD at this time (3). The initial stock of spare SRUs has been exhausted. The LRU repair process, therefore, is now being limited by the SRU repair rate (4). Base serviceable stock is zero by this time (5), and the number of serviceable aircraft is decreasing. The computed demand rate is responding to the increase in the actual demand rate. Consequently, SLQ is increasing and routine requisitioning continues. The depot continues to respond to this demand pressure by shipping on demand (6). This response is keeping the routine resupply rate higher than the NRTS rate (7). This indicates that the system is responding to the higher level of support

needed at the base by increasing the base stock level and decreasing the depot reserve stock level. Due to the high degree of smoothing in the daily demand computation, however, this stock redistribution response is unable to maintain an adequate level of base serviceable stock.

The analysis thus far highlights the consequences of a demand-pull inventory policy. At steady levels of demand that the system is able to sustain (week 17 to week 20) there is a continual stock shortfall (BSS less than SLQ). This shortfall can be accommodated by the system under these circumstances. If demand is steadily increasing, however, as it does in this experiment from week 20, the shortfall also increases continuously; it does not remain constant. As a consequence, total base serviceable assets decrease steadily even though the resupply rate is at the maximum demanded by the routine resupply decision structure (policy).

Week 27

At this time a slight shortfall in rate of effort is evident (1). As a consequence, the base is in a potential MICAP position (2), and in order to avoid raising MICAP requisitions, maximum effort is being demanded of base maintenance (3).

Also of significance at this time is that depot stock has not yet dropped below its initial level (4). This is a consequence of the heavily smoothed response of the daily demand computation. This high level of depot stock can also be interpreted as a consequence of the usual delay between the

outbreak of hostilities and the arrival of the first resupply shipment (if the routine resupply since week 24 is assumed to be negligible in comparison to the demand rate). Under this interpretation the model suggests that the first resupply will need to occur within 21 days of the outbreak of hostilities if a MICAP situation is to be avoided in the initial phase of the war.

Week 28

At this point the flying hour program reaches its maximum. The base, however, is not achieving the assigned program (1) even though some capability to increase aircraft utilization remains (2). This result was also observed in the previous experiment, and suggests that the flying hour program may need to be inflated if maximum aircraft utilization is the objective. It also suggests that the model may need to incorporate additional forces on aircraft utilization in the rate of effort determination structure.

This block also shows the speed with which the MICAP system has responded to base requirements. Within one week depot stock has dropped from surplus to near critical levels (3). As a consequence, depot repair is being expedited and, as discussed previously, the depot repair rate temporarily is exceeding the input rate to the depot (4).

Of particular interest is the increase in serviceable aircraft which is occurring at this time (5). The reason for this increase could not be determined from the analysis of

the graphical results, and is also not immediately apparent from the tabulated results. This behavior was not observed in the previous experiment and that observation provides the key to the cause here. In the previous experiment an instantaneous change was made to FHP. This resulted in the rapid onset of MICAP requirements which equally rapidly depleted depot reserve stock. The MICAP shipments, however, were only able to temporarily stop the decrease in serviceable aircraft, so why the difference here?

The explanation lies in the rate of change of the MICAP threshold with respect to the rate of change of the actual demand rate. In the previous experiment, an instantaneous change in the demand rate and the MICAP threshold occurred when FHP stepped to 900 hours per week. The MICAP threshold, however, at the time the increase was made, was less than the number of serviceable aircraft on hand. Therefore, when this threshold was subsequently penetrated, the MICAP response system transferred stock from the depot to fill base stock back to the MICAP threshold level which, in this instance, remained constant at 51.429 aircraft. Under these circumstances, an increase in base serviceable stock cannot occur.

In this experiment, however, both the flying hour program and the MICAP threshold are increasing at the time the MICAP threshold is penetrated. The MICAP system responds and attempts to resupply the base to the MICAP threshold level which, in this instance, is still increasing. The increase in the number of serviceable aircraft occurs because the rate of

increase in the MICAP threshold is greater than the rate of increase in the demand rate at the time. Because of the priority shipment delay, the peak of this increase does not occur until week 29.

Week 29

By this time depot stock has been depleted and the priority resupply rate is being limited by the depot repair rate (1). Routine shipments from the depot are no longer being made (2). The diversion of base work backlog to the depot is also now in progress at the maximum rate the depot is able to accommodate (3).

Week 30

At this time the maximum shortfall in the rate of effort occurs. This shortfall, however, is still not sufficient to force maximum aircraft utilization (see comments for week 28).

Week 33

The decrease in the flying hour program has, by this time, reduced the MICAP threshold to a point below the level of serviceable aircraft (1). Consequently priority shipments from the depot cease and depot stock begins to increase (2). (Recall that routine backorders are not satisfied until the depot MICAP reserve stock is re-established.) The base is once again meeting the flying program (3). Note that as the base is once again able to meet its flying commitments, the

operational requirements pressure component in the determination of RUSUR also decreases (4).

Week 34

At this time routine resupply from the depot reactivates, but is limited by the depot repair rate (1). The demand rate, however, is still much higher than the base LRU repair rate and depot resupply rate combined (2). Therefore, the number of serviceable aircraft continues to decrease (note that the maximum demand rate the system can sustain in the present circumstances is two LRUs per week).

Week 54

The flying hour program is now back to the normal peacetime level (1). The number of serviceable aircraft continues to decline, however, due to the high demand rate (2). Note, however, that the demand rate would be within the capabilities of the system were it not for the lower than normal MTBD due to the impact of quality (3).

Week 67

Prior to week 67 there is a gradual increasing trend in the MTBD. By week 67 this trend has resulted in an LRU demand rate which is less than the combined production rates of base and depot maintenance (1). Therefore, the number of serviceable aircraft begins to increase (2).

Week 69

The upward trend in MTBD noted at week 67 is still

evident at this time, and has reduced demand pressure to the point that some slow-down in the base workshop LRU processing rate has occurred (1). As a consequence to this slow-down, the quality of workshop output improves. This improvement in quality slightly reinforces the current increasing trend in MTBD (2). This reinforcement is in addition to that already being provided by the response of on-aircraft maintenance quality (QF1) to the increase in the number of serviceable aircraft (3). From this behavior it can be seen that under these circumstances, the relationship between increases in MTBD and quality constitutes a positive feedback loop (increases in MTBD lead to increases in quality which lead to increases in MTBD and so on).

Week 70 to 77

From week 70 to 73, a downturn in MTBD occurs. The steepness of this downturn, however, is not sufficient to cause a reversal of the increasing trend in MTBD due to improving quality of on-aircraft maintenance as of week 67 (the response of QF2 to the increasing number of serviceable aircraft), and the improving quality of workshop output as of week 69 (the response of QF1 to the decrease in workshop work rate). By week 74, therefore, MTBD is increasing again and, due to the reinforcement of increases in MTBD by the positive feedback link between the increases in MTBD and quality, the increasing trend in MTBD is maintained.

Week 99

At this time on-aircraft maintenance quality is back to normal and has no further impact on MTBD (1), and the impact on MTBD of low quality output from the base workshop during the period of high demand has been reduced to insignificance (2).

Week 106

The diversion to depot of base work backlog has stopped by this time (1). Note also, however, that depot stock is still at a critical level (2). Therefore, the reduction in the flow of reparables to the depot will soon lead to a reduction in the depot routine resupply rate. The consequences of this were discussed in the discussion of the results for the previous experiment.

Week 200

This final block highlights the fact that a flying hour program of 400 hours per week cannot be sustained by the system indefinitely. The average demand rate exceeds the combined maximum production capability of the base and the depot (recall that depot production is limited by the NRTS rate); hence the number of serviceable aircraft is decreasing steadily. The base workshop is responding to this steady decrease by continuing to repair all possible LRUs, as is indicated by the constant low value for USINVL (2). The LRU production rate, however, is limited by the SRU production rate (3) which, although being maintained at maximum, is inadequate. Consequently, the inventory of LRUs awaiting SRUs is steadily

increasing and, at this time, has reaches critical proportions (4). While this experimental result highlights the inadequacies of the SRU repair capability, the actual system would have taken action to avoid this situation. The model, however, shows action will be necessary and provides the means for determining what action to take and the possible consequence of this action. It also provides a means of determining how long corrective action may be delayed, or what the consequences of an unavoidable delay might be. This concludes the discussion of the tabular results.

Conclusions

The purpose of the experimental evaluation of the model was to determine its potential as a policy analysis tool. The results of the two representative experiments show the model is useful even in its present form, and can readily accommodate a wide range of policy options. The hypothetical scenario, in particular, provides a realistic illustration of the capability of the model to assist in the evaluation of policy options for increasing the ability of the system to respond to and sustain a high level of operations. The analysis of the results also demonstrated that no special training is required to use the model. The model represents the system in the same terms as managers and senior executives perceive it. The analysis of experimental results can also be made in those terms. This feature of the model enhances its usefulness as a policy analysis tool since it enables policy

makers to make their own interpretations of experimental results, and it also provides a means for clearly communicating those interpretations.

Summary

This chapter presented a detailed analysis of two representative experimental runs of the model. The experimental results obtained, and the level of analysis performed, demonstrated the potential of the model as a policy analysis tool. With the completion of this experimental evaluation, all the objectives of this research have been achieved with the exception of sensitivity analysis. The following chapter discusses the sensitivity analysis performed in this research.

CHAPTER 5

SENSITIVITY ANALYSIS

Introduction

The previous chapters have covered the development, verification, validation, and experimental evaluation of the model developed by this research. This chapter contains a discussion of the sensitivity analysis of the model, the final objective of the research. The purpose of sensitivity analysis is to determine the sensitivity of model behavior to changes in parameter values. The results of sensitivity analysis serve a two-fold purpose. First, they provide a guide to which parameters need to be accurately measured, or estimated, or perhaps need to be disaggregated so that the source of model sensitivity may be more clearly identified. Second, the results of sensitivity analysis indicate the sensitivity of the system being modeled to policy changes and, thereby, focus attention on the areas in which policy changes will have a significant effect on the whole system.

There are two aspects of system response which are of concern in sensitivity analysis. First is what is referred to in this research as final value analysis. Final value analysis is concerned with the magnitude of the change in system behavior which results from a change in one or more parameters.

The second concern is the transient response of the system behavior to parameter changes. Transient response analysis is concerned with the rate of response to parameter changes, and the form of the response (linear trend, exponential growth or decay, continual cycling). Both these aspects of sensitivity analysis are important, but their relative importance is dependent upon the purposes for which a model is being used. The sensitivity analysis conducted in this research gave equal emphasis to both aspects.

Basis of Analysis

The following analysis is based on the insights gained from the developmental and verification runs of the individual sectors and progressive combinations of sectors, experimental design runs, and finally, the experimental runs described and discussed in the previous chapter.

To facilitate discussion and highlight the possible sources of sensitivity, the discussion of the sensitivity analysis results is divided into four sections. These sections in order of presentation are:

1. Principle Parameters
2. Table Functions
3. Representation of Quality
4. SRU Repair Process

Principle Parameters

As a general observation the sensitivity analysis

showed that model behavior is not significantly affected by small variations in parameter values. Large changes in certain parameters, however, can have a significant effect. These principle parameters are discussed in this section.

Number of Aircraft

The number of aircraft (NAC) is a fundamental determinant of system behavior. Of concern from a sensitivity analysis point of view, however, is the manner in which changes to the number of aircraft occur. In its present form, the model assumes a fixed number of aircraft. The number is under the control of the model user and, hence, presents no sensitivity problems. If, however, a need aris s to include a variable number of aircraft to represent attrition or a progressive build-up in force size, care will be required in how this variability is incorporated into the model. The number of aircraft directly or indirectly affects a number of the principle variables in the model. While the manner in which the number of aircraft is used is valid in the present form of the model, it may be invalidated by interaction between the process which varies the number of aircraft and the other processes in the system.

Mean Time Between Demand

The mean time between demand (MTBD) is represented in the model by a sampling distribution, and is the only source of random variation in the model. The basis of the distribution in the model was discussed in Chapter 3; of interest

here is the sensitivity of model behavior to changes in the mean of this distribution. Also of relevance are the implications of using a distribution to represent this parameter rather than simply the mean as is done with the other variable parameters in the model.

The experimental runs of the model showed that the behavior exhibited by the model can be affected significantly by changes in the mean of the MTBD distribution (the impact of quality). Under normal circumstances, however, the mean of the MTBD distribution will be a relatively constant characteristic of the system. Therefore, from a sensitivity analysis point of view, the only concern is that the mean and variance of the MTBD sampling distribution be measured with reasonable accuracy. High accuracy is not required since the model is not sensitive to small variations. On the other hand, the MTBD distribution can change significantly depending upon how demands are defined. It is this source of change which is of prime concern in this discussion.

The model represents the MTBD as a sampling distribution. This enhances the adaptability of the model in that any definition of MTBD can be incorporated by simply changing the mean and variance of the MTBD distribution provided in the model (this is a consequence of the Central Limit Theorem of statistical analysis which, among other things, states that most sampling distributions are normal distributions). This transparency of the model to how the MTBD is defined can, however, lead to false conclusions regarding the comparison of

experimental results if the results being compared are based on different MTBD definitions.

This problem of differing definitions is not peculiar to the definition of MTBD. It also applies to most of the other parameters in the model and is not a problem peculiar to this research. It applies to virtually all research. It is highlighted here, however, because it is a potential source of misuse of the model and, more particularly, because there are a number of definitions for mean time between demand in current use.

The second point about model sensitivity to MTBD concerns the relevance of employing a distribution for this parameter rather than the mean of a distribution as is done with most of the other parameters in the model. There are two reasons for treating MTBD differently; both have relevance in sensitivity analysis. The first reason is that the MTBD is probably the most significant source of random variation in the performance of the reparable assets system. Therefore, by incorporating this variation the realism of model behavior is enhanced. If, however, the variance of the MTBD distribution is relatively low, the sensitivity analysis carried out in this research shows that there will be no significant difference between the results obtained with MTBD as a single value, and the results with MTBD as a distribution. The second, and more important point, is that unlike the other parameters of the model, much of the variation in MTBD is beyond the immediate control of management. It is a result

of the mean time between failure inherent in the design of the particular asset. Incorporating MTBD as a distribution highlights this uncontrollable nature of MTBD, and forces the user of the model to acknowledge it in the interpretation of the results.

Delay Constants

The sensitivity of model behavior to changes in the delay constants depends upon the significance of the rate associated with the particular delay. The model's behavior, however, is only significantly affected if relatively large changes are made to delay constants. Therefore, in general, the accuracy of the delay constants is not critical.

Depot Maximum Throughput

The model is not sensitive to changes in the depot maximum throughput (DMAXTP) whenever the diversion to depot rate process is not in operation. Once the diversion to depot rate (DTDR) activates, however, the combination of a high demand rate, as is the case in the experimental runs, with a high DMAXTP can significantly affect the behavior of the model. A high DMAXTP under these conditions slows down the rate of decrease in serviceable aircraft and, therefore, enables the base to sustain an excessive flying hour program for a longer period. In view of this sensitivity, it is important to appreciate the limitations of the representation of this process in the present model.

In this research it was not possible to develop a

detailed representation of the depot repair process. Therefore, although the aggregated representation of this process in the present model satisfies the objectives of the research, it may not be adequate for a study in which the response of the depot repair process is a critical factor.

Condemnation Proportion and Acquisition Leadtime

The depot acquisition process has a negligible effect on model behavior for any reasonable values of its parameters; condemnation proportion (PROPC) and leadtime (LDTIME). It must be noted, however, that the present model does not fully represent the reacquisition process. Only reacquisition to replace condemnations is represented; reacquisition to cover increased requirements is not. Nevertheless, sensitivity analysis of the present simplified representation suggests that because of the long leadtimes involved, a more comprehensive representation of the acquisition process is unlikely to significantly affect the short- to medium-term behavior of the model. A possible exception to this conclusion would be a large, one-time reacquisition. This, however, could be easily incorporated into the current model as a separate input to depot serviceable inventory which is activated at the time the buy decision is made, and incorporates an appropriate delay representing the manufacturing leadtime and the delivery schedule.

Table Functions

There are two areas of concern in the sensitivity analysis of table functions, namely: parameter sensitivity and form sensitivity. These aspects are discussed separately in the following sections.

Parameter Sensitivity

A significant proportion of the behavioral aspects of decision-making and the constraints on the implementation of decisions are embodied in the table functions of the model. This has been achieved by designing each table function around a parameter which represents the maximum or minimum action limit of the particular dependent variable. These parameters, therefore, represent performance limits in the system. As a consequence, the model behavior is sensitive to changes in these parameters. This is to be expected given the fundamental nature of these parameters. This does not imply, however, that the parameters for the table functions must be highly accurate. The behavior of the model is not affected by small changes in table function parameters. For example, small increases or decreases in the parameter MAXTP (maximum LRU throughput capability of the base workshop), which is used in the repair rate factor table functions, will cause changes in the final value and transient response behavior of the model. The basic behavior exhibited by the model, however, is not affected. Therefore, the significance of the results for policy analysis is not affected.

Table function parameter sensitivity is only of concern if large changes in the table function parameters are contemplated or if large variations in these parameters are experienced in practice. Contemplated changes are under the control of the model user and, therefore, do not present a problem. Large variations in practice are a problem.

In this research the table functions were designed around parameters which should not vary significantly, in practice, except as a result of a significant change in policy. If further research into these parameters proves this is not the case, the structure of the model in the affected areas will need to be changed to account for the observed variations.

Form Sensitivity

Table function form sensitivity concerns the upper and lower limits of the function and the form of the function between those limits. The limits of the function are related to the parameter on which the function is based. Therefore, the limits are only of concern if the model user wishes to change these limits rather than change the value of the parameter. The table functions have been designed to minimize the need for this type of change. Moreover, under normal operating conditions, the table functions should be operating somewhere between the limits. Therefore, the limits will only be significant if behavior at the limits of system capability is being studied. Under these conditions, the comments on parameter sensitivity also apply to the limits of the table function.

The behavior of the model is not particularly sensitive to the form of the table function between the specified limits. Provided, of course, that the form of the function captures realistic behavior. The forms of the table functions developed in this research were designed with this correspondence to actual behavior in mind. The realistic behavior exhibited by the model suggests this correspondence has been achieved. At this stage, however, the forms of the table functions represent hypotheses which remain to be confirmed by further research. Assuming that the research will show these hypotheses to be correct, the sensitivity analysis conducted in this research shows that slight variations in actual shape (slope, length of linear region) will not affect significantly the behavior of the model. The table function for the Realized Aircraft Utilization Factor (RAUF) may be an exception to this conclusion.

The top of the linear region of the RAUF table function is used in the determination variable threshold in the priority depot requisitioning (MICAP) decision structure in the model. Considering the inherent responsiveness of the MICAP decision structure, changes in the shape of the RAUF table function may affect significantly the behavior of the model.

Finally, the sensitivity of the model to changes in the shape (not limits) of table functions is also dependent on the experimental conditions. If the experiment involves a rapid transition of the table function output from one limit

to the other, shape is not particularly important. On the other hand, if the experiment involves final value analysis and the table function is operated over a range of values between its limits, the influence of shape will need to be considered.

Representation of Quality

The experimental results show that the representation of quality can have a significant effect on model behavior. The present representation disaggregates quality into two components which have significantly different response times with respect to their effect on the rate of demand. The quality of on-aircraft maintenance responds quickly to increases and decreases in the demands of the flying hour program, and has a directly proportional effect on the demand rate (via a decrease in the mean of the mean time between demand (MTBD) distribution). The range of action of the quality factor (QTAB1), therefore, can have a significant effect on the behavior of the model at flying hour program levels near the limit of system capability. The quality of base workshop output, on the other hand, responds only when the workshop is operating at maximum throughput (MAXTP), and has a progressive effect on MTBD, which depends on the time the workshop spends at MAXTP. Because of this progressive effect of workshop output quality, this quality factor only significantly affects model behavior if the range of action of this factor is relatively wide (QTAB2), or if the

combination of this factor with the on-aircraft maintenance quality factor results in a significant reduction in MTBD.

Sensitivity analysis shows that the effects of quality are only significant at flying hour program or demand rate levels near or above the capability of the system. For the present parameters in the model, this limit is about 500 flying hours per week, or a demand rate in excess of two LRUs per week. At this level of activity, the effects of quality tend to reduce the MTBD. This causes an increase in the demand rate which, via the quality effects, causes a further reduction in MTBD. Note that this is a positive feedback loop. In the limit this process will result in a lower mean for the MTBD distribution. How much lower depends upon the combination of the lower limits for the *quality factor tables* QTAB1 and QTAB2. Of importance from a sensitivity analysis viewpoint, is that this process can result in the MTBD remaining permanently at this low quality limit. The model, and hence by implication the system, will only return to the normal MTBD distribution if the flying hour program is significantly reduced for a period long enough to allow a reversal of the quality effects process.

The implications of this sensitivity analysis for the reparable asset system are significant. If the system is continually operated near maximum capability, the analysis shows that quality effects may result in a demand rate which is permanently higher than that which is inherent in the design of the particular reparable asset or assets. Moreover, this

situation will not be apparent to managers, and action taken by them to reduce the demand rate is not likely to redress the real cause of the demand rate being higher than anticipated.

The foregoing discussion has highlighted the sensitivity of the model to the representation of quality effects and the implications this sensitivity has for the reparable asset system. With regard to the further development of the model, these results indicate that the parameters in the present representation may be critical in the interpretation of the behavior of the model. Therefore, further research into the representation of quality will be required if the model is to be used for studies involving extended periods of operation at or above system maximum capability.

SRU Repair Process

The experimental runs of the model showed that the SRU repair process can significantly affect the ability of the system to sustain a high flying hour requirement. Whether this 'SRU limiting' occurs depends upon the relationship between the base LRU repair process maximum throughput capability (MAXTP), the SRU generation factor (SRUGF), and the SRU repair process maximum throughput capability (MTPSRU). The implications of these relationships were addressed in the discussion of the results for experimental run one. This discussion concluded that further research into the representation of the SRU generation and consumption process, represented by SRUGF, was needed. Nevertheless, the present

representation does produce meaningful results and provides an insight into the sensitivity of the system to certain parameters.

Assuming that the SRU generation factor (SRUGF) adequately represents the underlying processes, sensitivity analysis shows that the SRU process will not significantly affect the behavior of the model provided MTPSRU is high enough. If MTPSRU is equal to or greater than the maximum rate the LRU diagnosis process can generate reparable SRUs, the SRU repair rate will only limit the LRU repair rate while the system is adjusting to an increase in the LRU demand rate. If, however, the base has sufficient stock of spare SRUs, even this temporary limiting of the LRU repair rate will not occur. Therefore, the behavior of the model will only be influenced by the SRU sector if MTPSRU is low relative to MAXTP, or if the base stock of spare SRUs (BSRU) is low relative to the average SRU consumption rate and the rate of response of the SRU repair rate to increased demand for SRUs. Whether these conditions occur depends on the value of the parameter SRUGF. Hence, the need for further research into the representation of the SRU generation and consumption processes. This factor may need to be replaced by a distribution similar to the mean time between demand distribution for the LRU process. There are similarities between the process which generates reparable LRUs and the process which generates reparable SRUs. Viewed from this perspective, the SRUGF may also need to be varied according to quality effects very similar

to those of the LRU process. These possibilities could not be pursued in this research. They are, however, indicative of the level of analysis required and highlight the simplification which the SRU generation factor presently represents.

On the basis of the foregoing sensitivity analysis, the value for SRUGF for the experimental runs was chosen so that the consequences of a limited SRU repair capability could be investigated. The remaining parameters in the SRU process are estimates for the actual values.

Summary

This chapter presented the results of the sensitivity analysis carried out on the model developed by this research. The implications of these results for the application of the model in policy analysis and the further development of the model were discussed. The following chapter summarizes the research and presents the conclusions and recommendations for further research.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

The main objective of this research was to develop a system dynamics model which demonstrates the impact of policy changes on the availability of serviceable aircraft reparable assets at base level. The specific subobjectives, as presented in Chapter 1, were to:

1. identify the major processes of the reparable asset system;

2. analyze the elements of those processes, their structure and relationships, and the attributes of the elements and relationships;

3. construct a system dynamics and mathematical model of the reparable asset system;

4. develop a computerized model from the system dynamics and mathematical models of the system;

5. verify the performance of the model, and validate that the model represents the system;

6. evaluate the model as a policy development and analysis tool; and

7. identify areas of concern for policy-makers.

This chapter will summarize the research effort as

it relates to each of the objectives. Following the summary, some conclusions about the model and the reparable asset system will be presented. The last section of this chapter will contain recommendations concerning further research with the reparable asset system model.

Summary

The first objective of this research effort was to identify the major processes of the reparable asset system. This was done by conceptualizing that system as consisting of six major process sectors: demand rate generation, base-level LRU and SRU repair, the impact of quality, routine requisitioning, depot repair, and depot resupply. Within and between each of these sectors the major cause and effect relationships were identified. This led to the accomplishment of the second objective.

The second objective of this research was to identify the elements of each of the processes, their structure and relationships and the attributes of the elements and relationships. This was accomplished by a process of analysis and measurement that relied on the researchers' experience with the system, interviews with logistics managers, and a detailed literature review. The results of this analysis and measurement of the reparable asset system processes were presented as a system dynamics flow diagram and the accompanying system of equations, thus satisfying the third objective of the research.

The fourth objective of the research effort presented

here was to develop a computerized model of the reparable asset system. This was accomplished by translating the flow diagram and system of equations into equations in the DYNAMO simulation language and running this simulation on the computer.

The fifth objective was to verify and validate the system dynamics computer simulation model. Verification consisted of carefully following the computational sequence of each sector, both on its own and in combination with the other process sectors. In every case, it was ascertained that the system of equations in the model performed as intended. The validation process was undertaken to insure that the model adequately exhibits the behavior of the real system, and that the model served the purpose for which it was intended. The first part of validation was accomplished through an open-ended interview process in which the model was reviewed with logistics managers and professors of logistics management. This process including checking the system boundaries, reviewing the model for any gross errors, comparing the model's structure to that of the system, checking the correctness of parameter values, and finally, insuring that the model could reproduce system behavior.

The second part of the validation process, insuring that the model served the purpose for which it was intended, accomplished the sixth research objective. This evaluation was accomplished by conducting two experiments with the model and evaluating the results to see how well the model described

the dynamics of system behavior under the constraints of current policy.

In the process of accomplishing the first six research objectives, sufficient confidence was built up in the model to make some general conclusions about the reparable asset system and areas of concern for policy-makers. These conclusions are included in the next section. The seventh objective was accomplished as a part of the sensitivity analysis carried out on the model, and led to certain recommendations for further research.

Conclusions

The reparable asset system is a goal oriented, feedback control system that displays the counter-intuitive behavior characteristic of complex systems. The goal of the system is to provide adequate supplies of serviceable assets at base level which, in turn, is but one component of weapon system readiness. Despite wide agreement among logisticians about the goal of the system, there is less agreement on how best to achieve this goal. This disagreement, in turn, stems from a lack of understanding about how the system as a whole reacts to changes in its component parts.

The primary goal of this research was to develop a system dynamics model of the reparable asset system that would assist policy-makers to assess the implications of current and proposed logistics policy on the performance of the system. Within the limits of the current study, this has been

accomplished. As a consequence of achieving this goal and the experimentation and analysis done with the model so far, several observations can be made:

1. The routine depot maintenance and resupply processes, in combination with base maintenance capability, can adequately support base-level LRU requirements if the flying hour program is within the vicinity of normal peacetime training levels. In systems terms, this suggests that the current decision structure of the reparable asset system provides the requisite variety of responses to control the system and sustain a moderate flying hour program.

2. When the flying hour program exceeds moderate values, the reparable asset system is unable to sustain these higher requirements indefinitely, and eventually enters into a continual trend of collapse. The average level of serviceable assets at the base continuously decreases. The strength of this trend depends on how much the flying hour program exceeds the maximum normally supportable level. Consequently, in certain situations system managers may be unaware of this collapse trend.

3. The priority requisitioning process cannot reverse the collapse trend, once started, though it may forestall further collapse for a period of time. Once depot stocks are reduced to critically low levels, however, nothing within the reparable asset system will prevent the collapse from continuing indefinitely over the short run.

4. The only action that will prevent the collapse

of the system is a fundamental change such as increasing base or depot level repair capability. However, for LRUs with a high percentage of base repair, increases in depot repair capability cannot improve the situation significantly unless a significant proportion of the build-up of reparables at the base is transferred direct to the depot without prior NRTS assessment.

While the foregoing observations about the reparable asset system might not be unexpected, the power of the model as a policy analysis tool is that it clearly demonstrates the occurrence of these events and provides a measure of the time scale over which they occur. Further, it suggests what information can be used to assess the time behavior of the system and what processes cause the system to behave the way it does. This is significant to policy-makers since it carries implications for the design of information and control systems.

Finally, because the model is expressed in the common language and symbols used by logistics policy-makers, it is readily usable by these managers. As opposed to other more traditional analysis techniques that require users to possess a high degree of specialized knowledge, the system dynamics model requires a minimum of familiarization with the technology involved. Thus, if the manager can specify the proposed policy options, they can be included in the model and their impact on system performance compared.

The conclusions presented here are justifiable within the limitations of the model developed in this research.

Computer modeling and dynamic system analysis in general are iterative processes. There is no one, final model of any system. The system modeled changes over time (8; 25). The model itself may generate further insights into the modeled system and suggest new ways of looking at problems, new experiments, and even new policies (22:xviii-xix). So it has been with this research.

Recommendations

General Recommendations

This research has produced a valid, operational policy analysis model of the Air Force reparable assets system. This model is useful in its present form and has the flexibility and adaptability to be able to be used in the evaluation of a wide range of policy options. The following recommendations are made:

1. The model be adopted as an aid in the development of policy for the Air Force reparable assets system.

2. A long-term commitment be made to the further development and expansion of the model so that it may realize its full potential as a policy analysis tool.

Recommendations for Further Research

The results of this research indicate that research at several different levels would be fruitful in increasing the current understanding of reparable asset system behavior and the impact of policy on that behavior.

First, the sensitivity analysis of the model suggested several areas of further research in order to refine the processes presented and represented in the model. The principle recommendations of the sensitivity analysis are:

1. Research be conducted to confirm the form of the table functions used in the model;

2. The representation of quality effects be developed further so that the source of system sensitivity is more clearly defined and can be controlled;

3. The representation of the SRU generation and consumption processes be developed in more detail so that the interaction of the LRU and SRU processing systems can be more closely analyzed; and

4. The representation of the depot repair and reacquisition processes be disaggregated so that the implications of policy changes in these areas may be more explicitly demonstrated by the model.

The second line of effort concerns further elaboration of the scope of the model. The model, as presented here, addresses the major processes relevant to a multi-level, single-item representation of the reparable asset system. It became apparent during the research leading to the development of the model that several important processes could not be fully represented within the scope of this model. Some of these are: the impact of cannibalization policy on weapon system readiness; the impact of maintenance managers' decision structures on the competition between several items for limited

maintenance capability; the impact of centralized intermediate repair on weapon system readiness; the impact of distribution policy on the competition between users for scarce depot resources; the impact of multiple users on depot requirements computations. Each of these topics and many others would require considerable elaboration of several, or perhaps all, of the current model sectors. The current model provides a basis for this research; the importance of the questions involved should provide the impetus.

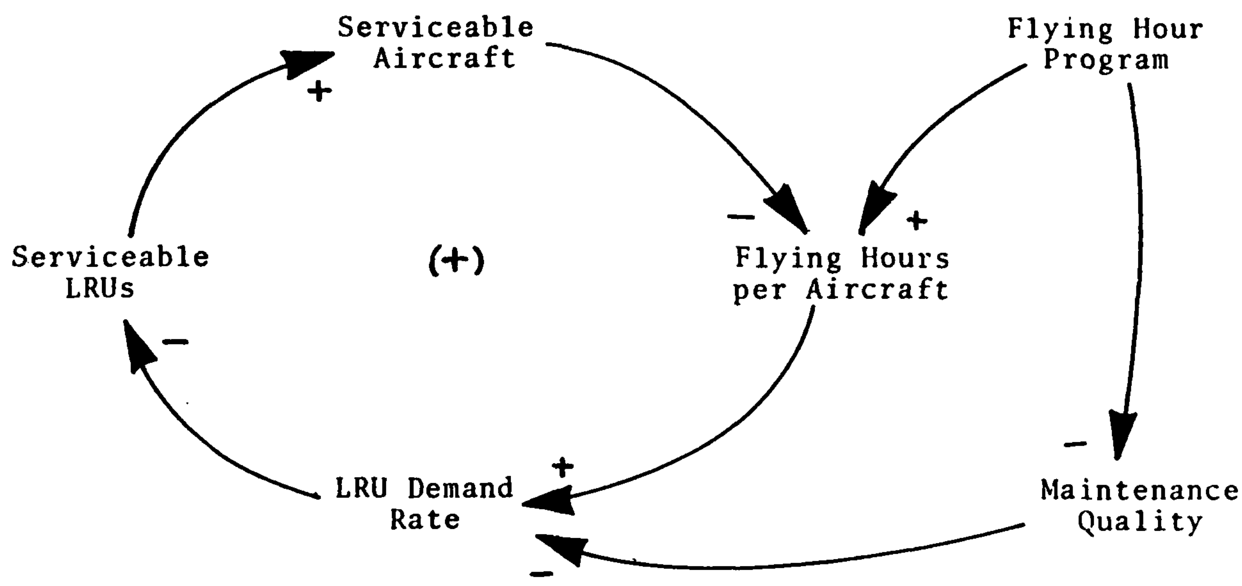
The final line of recommended research effort concerns the relationship between the reparable asset system and the Air Force logistics system of which it is but a part. It seems probable that, due to their complexity, other major subsystems in the logistics system (major modifications, acquisition, expendable supplies, etc.) have an impact on reparable asset policy and that, in turn, reparable asset policy impacts these logistics subsystems. An effort (2) is currently underway to develop policy analysis models of the other logistics sub-systems. It is recommended that this research effort be given the fullest support in light of the benefits that would be gained through a thorough understanding of the logistics system.

In summary, the system dynamics model of the reparable asset system reported here shows promise as an analysis tool for logistics policy-makers. In addition, this model can serve as a seminal work from which many further studies can grow, all of which could potentially increase the ability

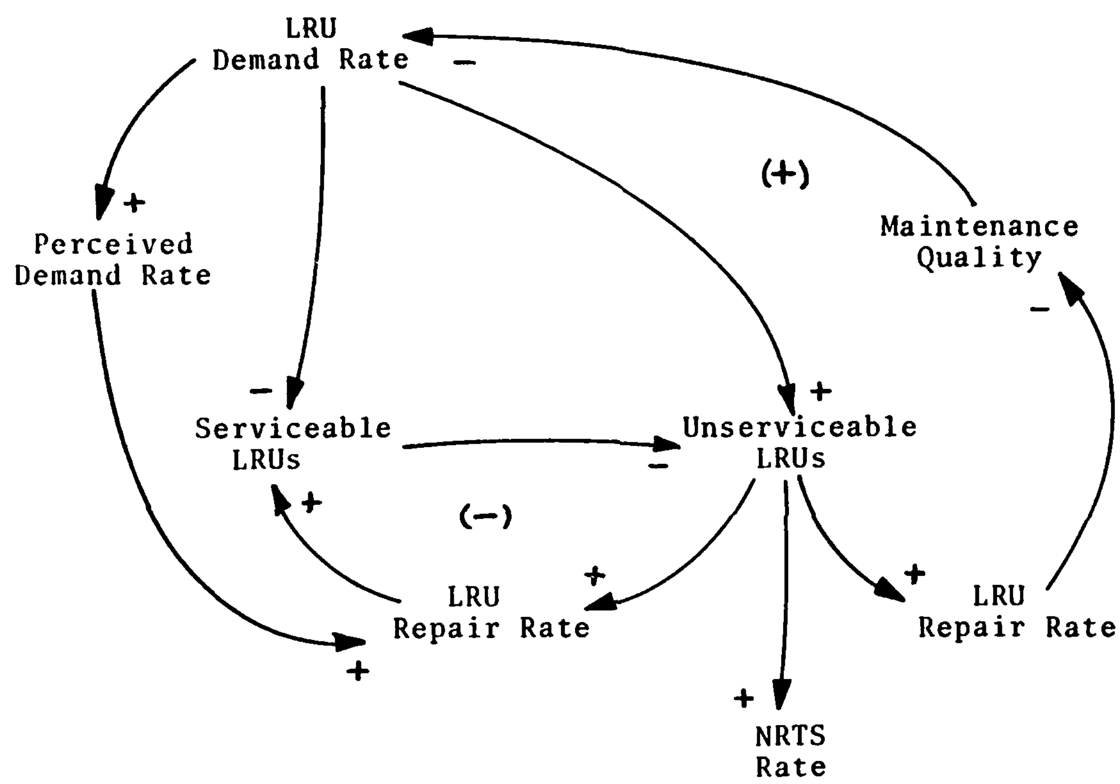
of logistics managers to deal with the challenges presented to them by the dynamics of the system they manage and the environment in which it exists.

APPENDIX A

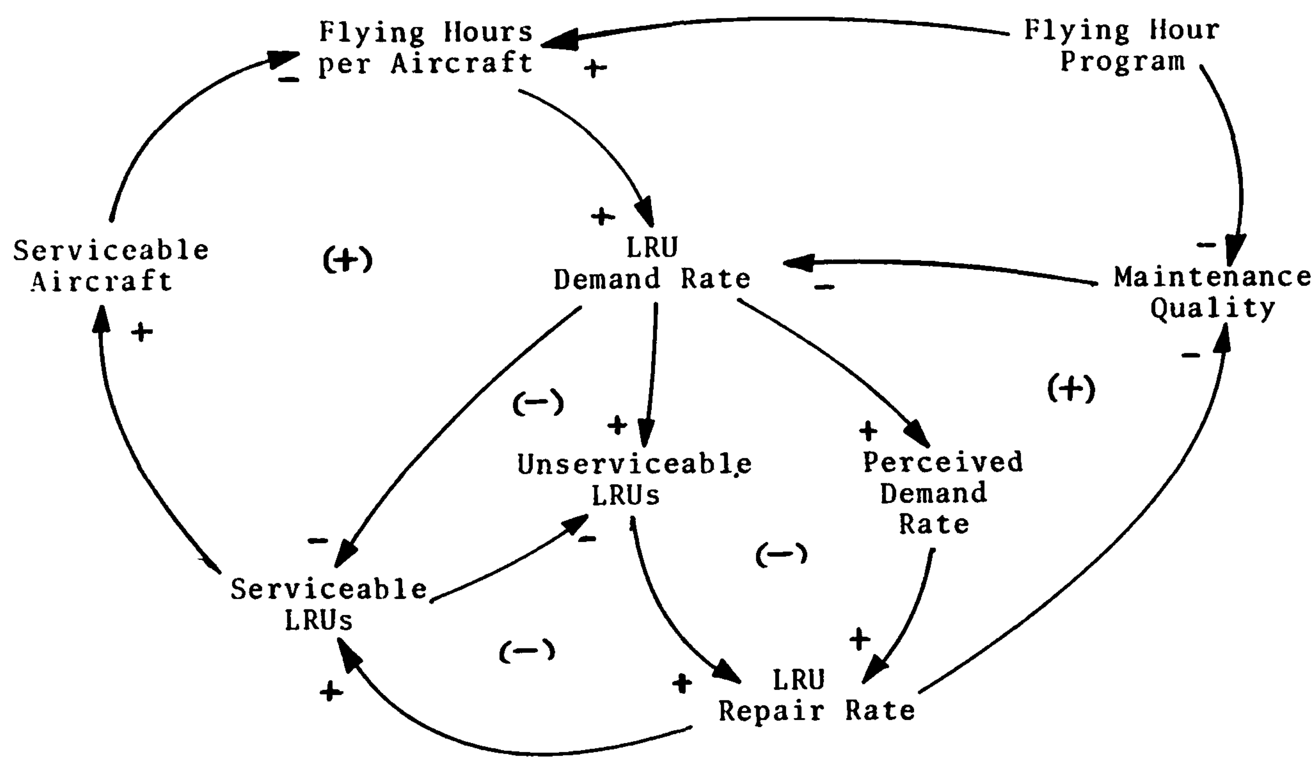
CAUSAL-LOOP DIAGRAMS



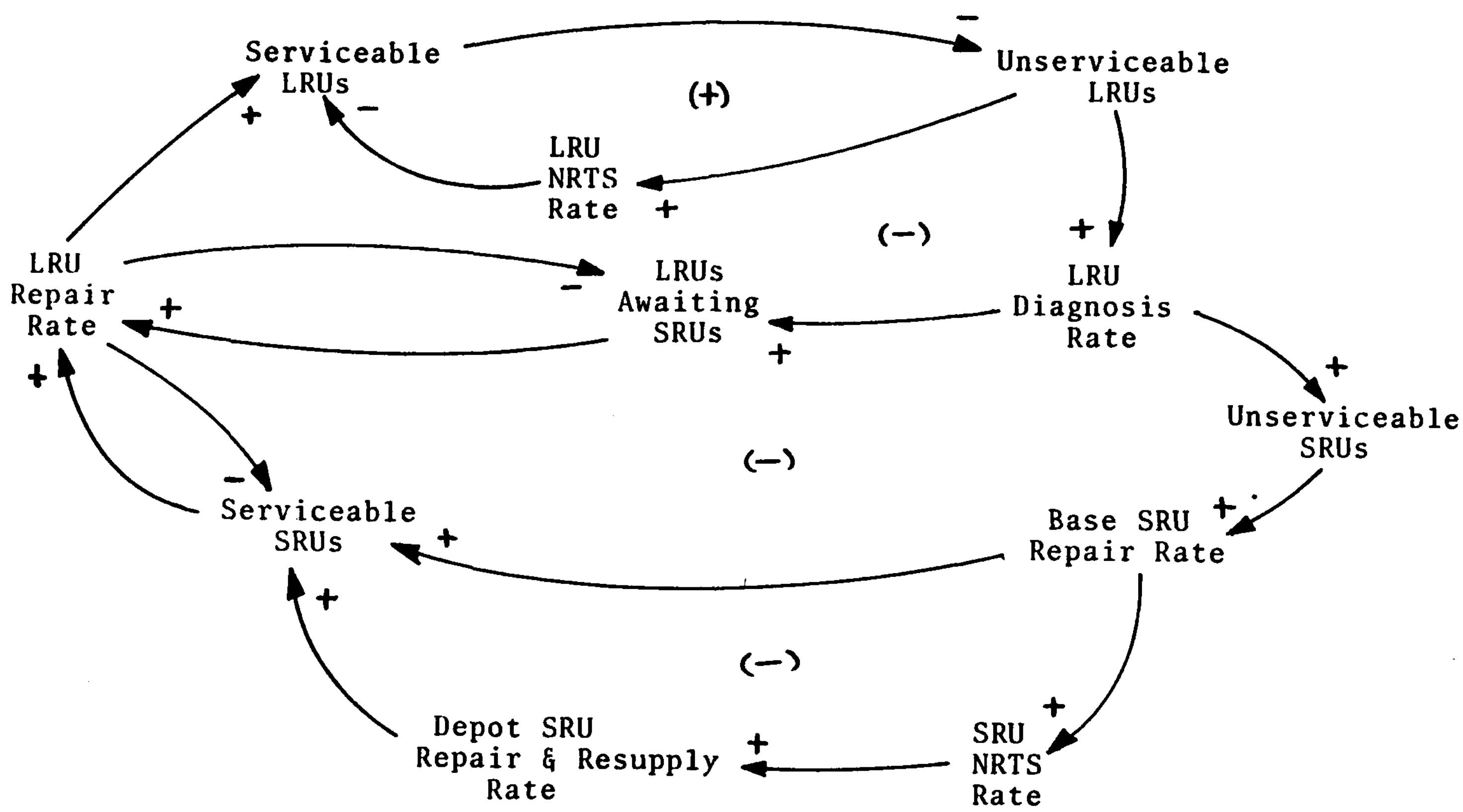
Causal-Loop Diagram for LRU Demand Rate Sector



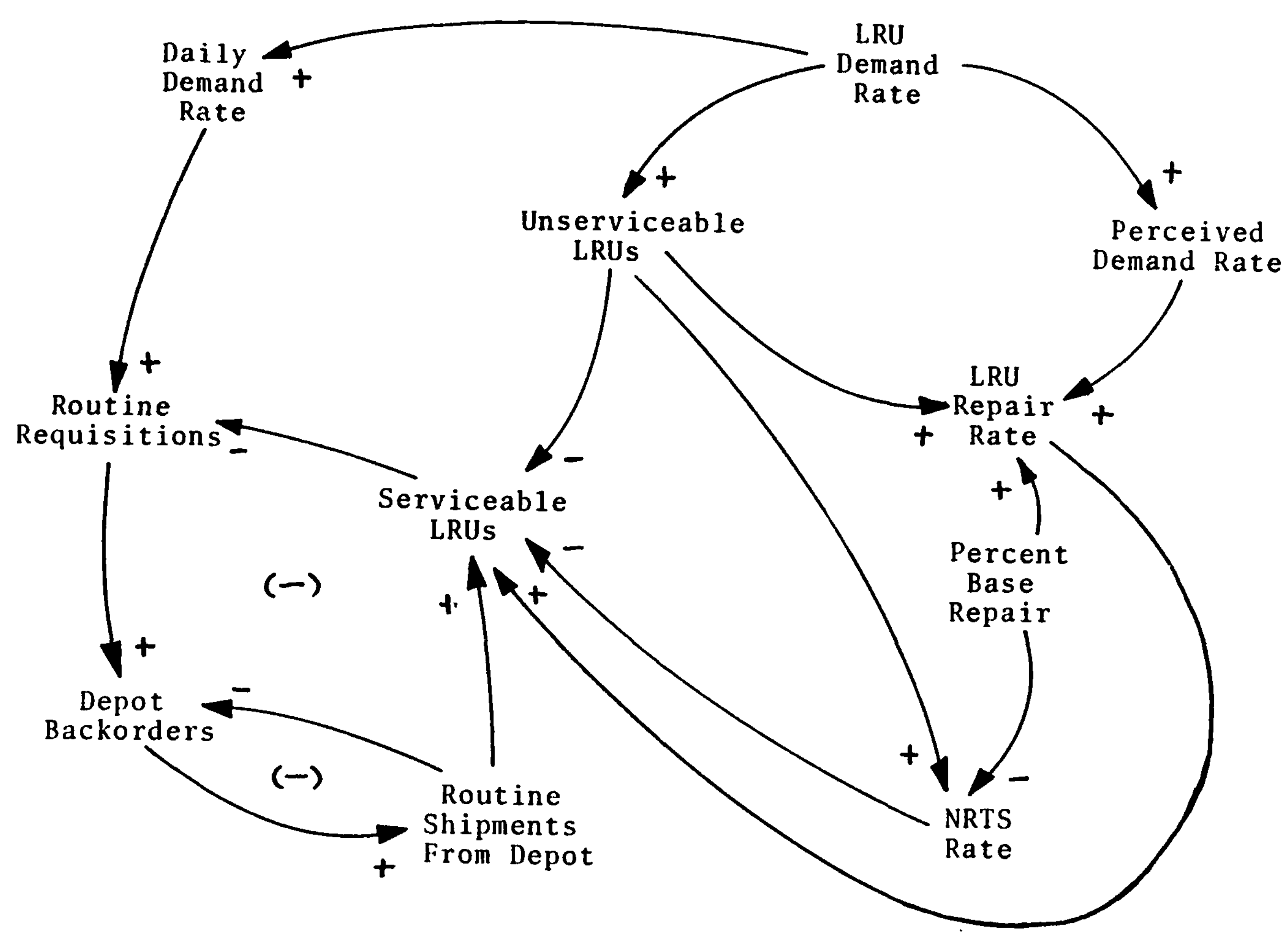
Causal-Loop Diagram for Base LRU
Repair Process



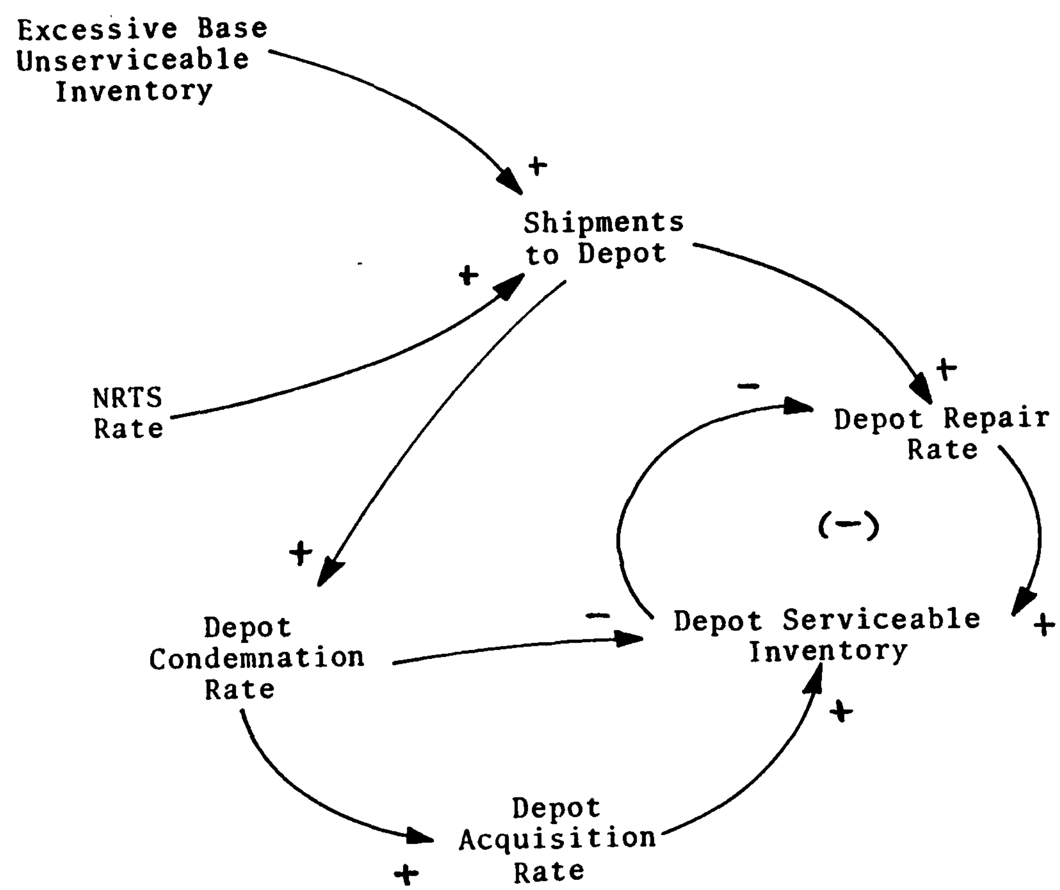
Causal-Loop Diagram for Quality Effects Sector



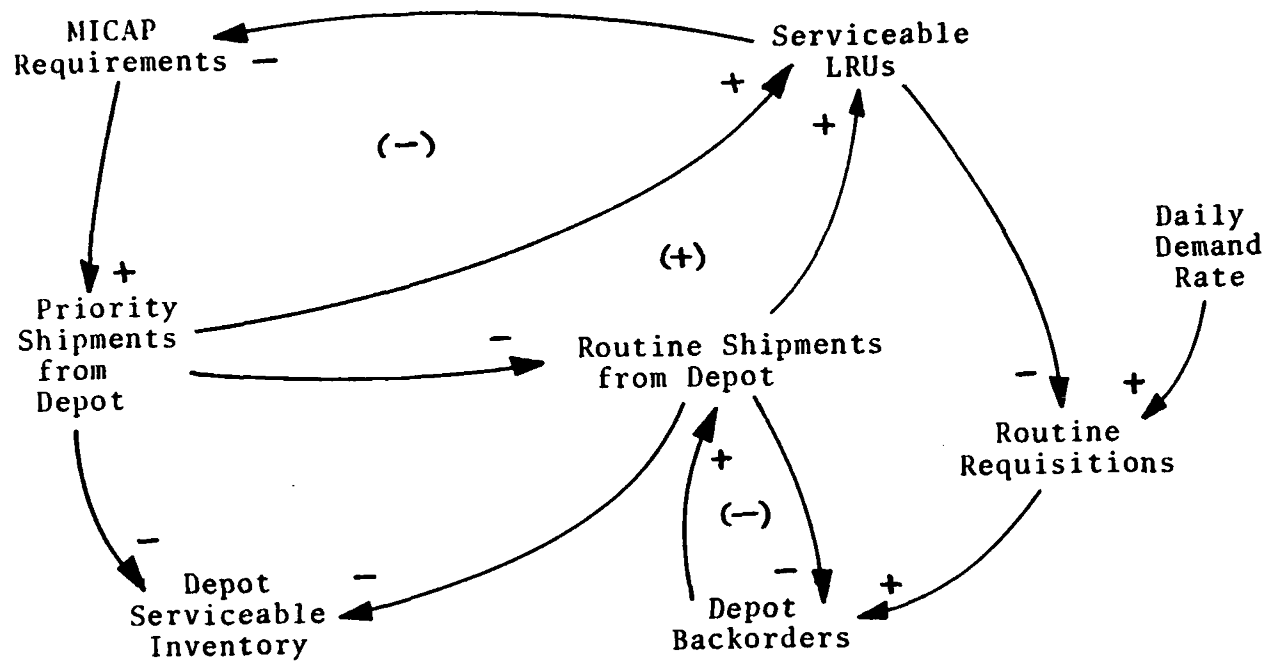
Causal-Loop Diagram for Base LRU and SRU
Repair Process Sector



Causal-Loop Diagram of Base Level Routine Requisition Process Sector



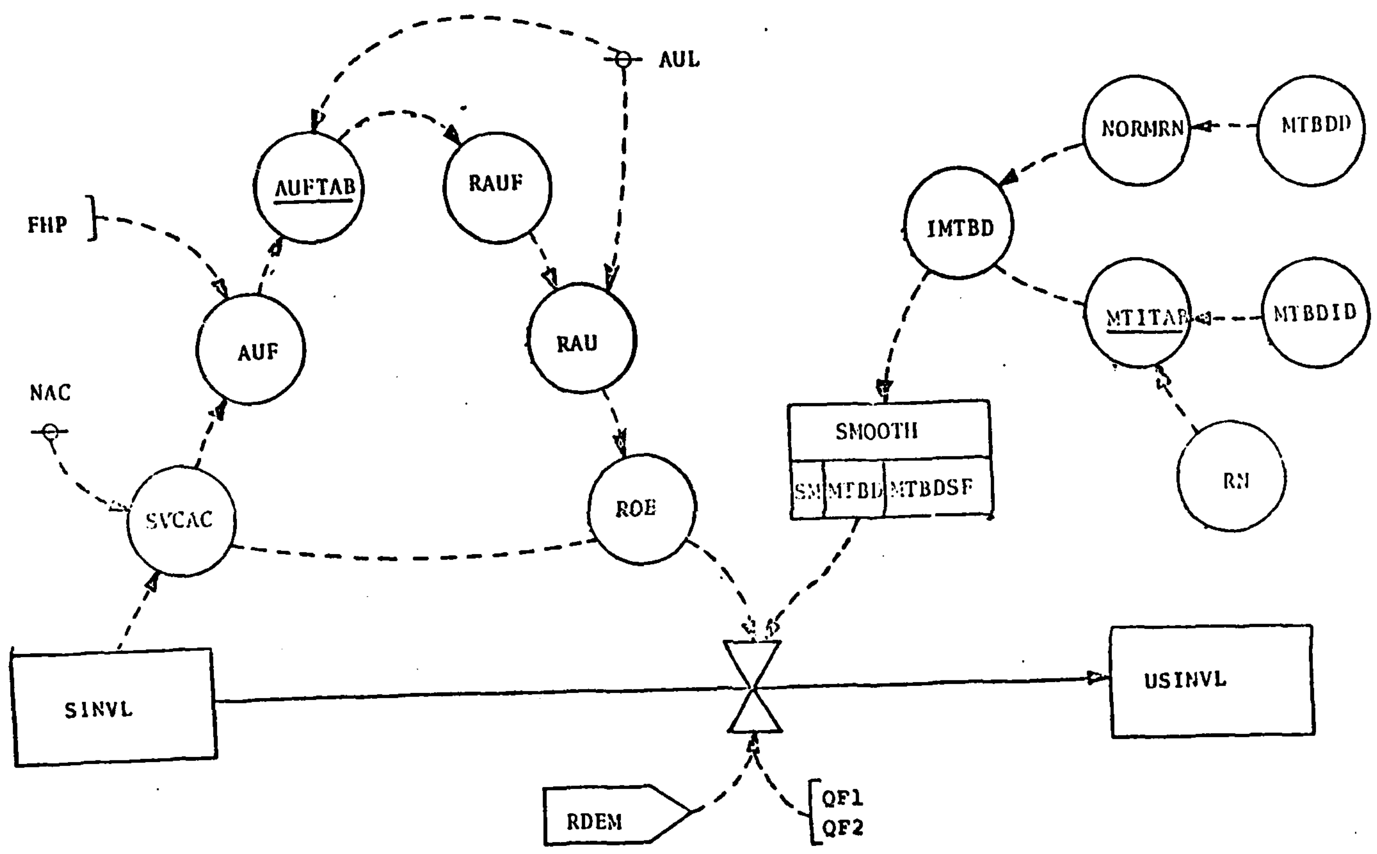
Depot Repair Process Sector Causal-Loop Diagram



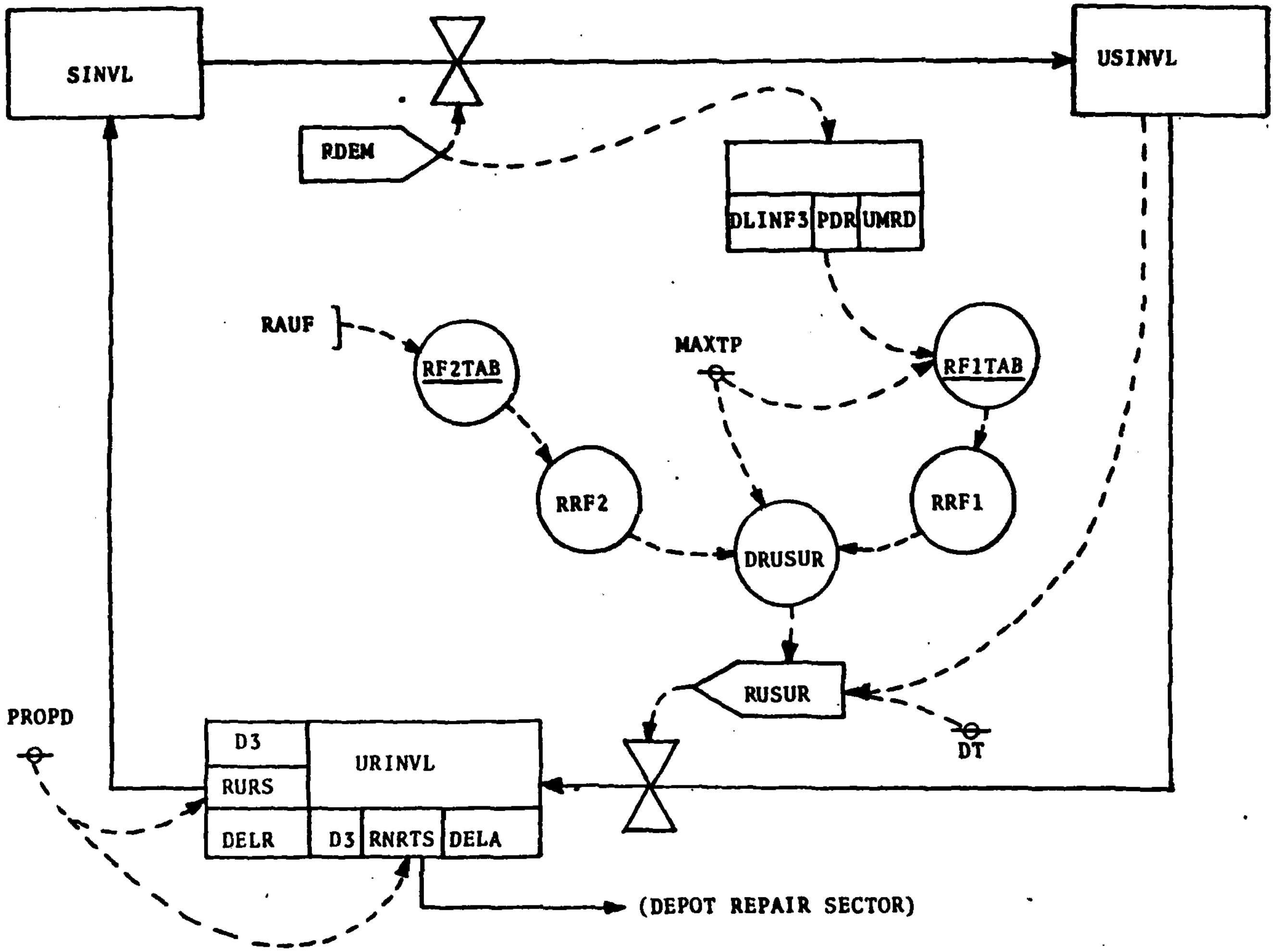
Causal-Loop Diagram of Depot Resupply Process Sector

APPENDIX B

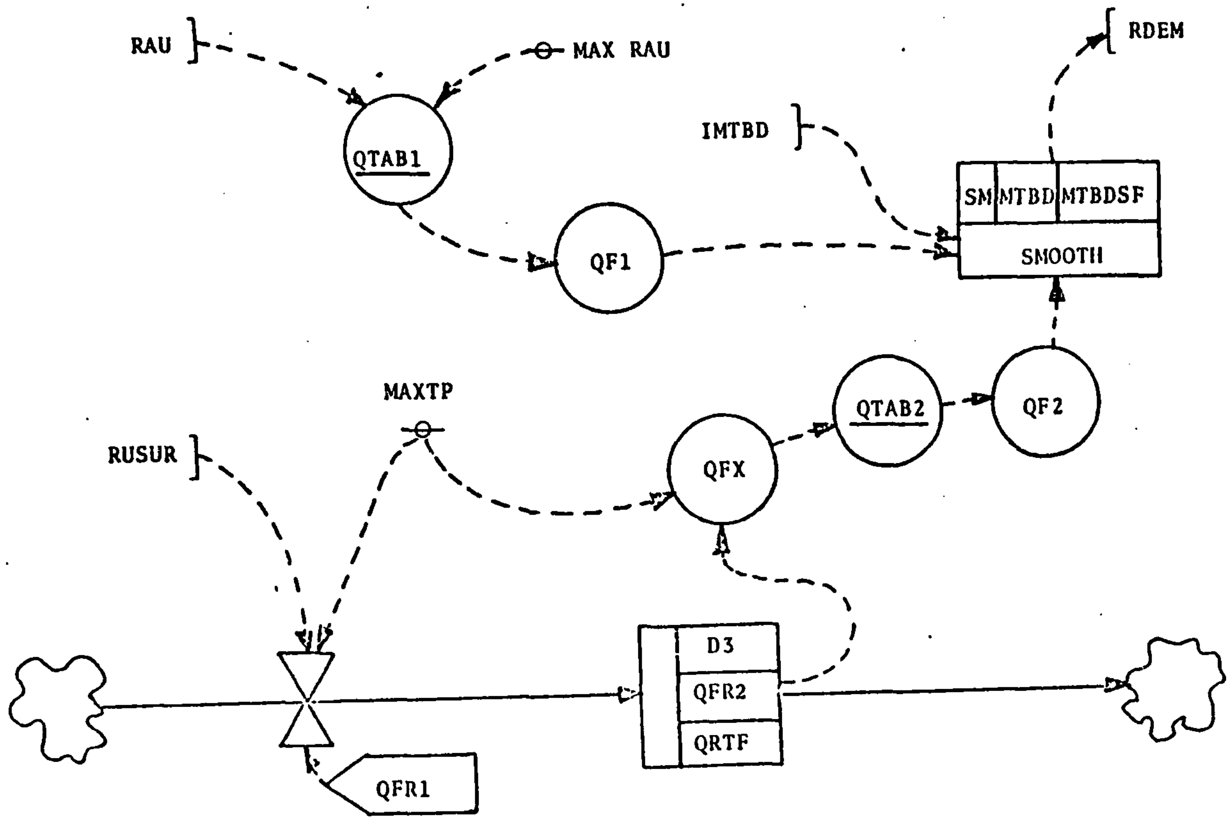
FLOW DIAGRAMS



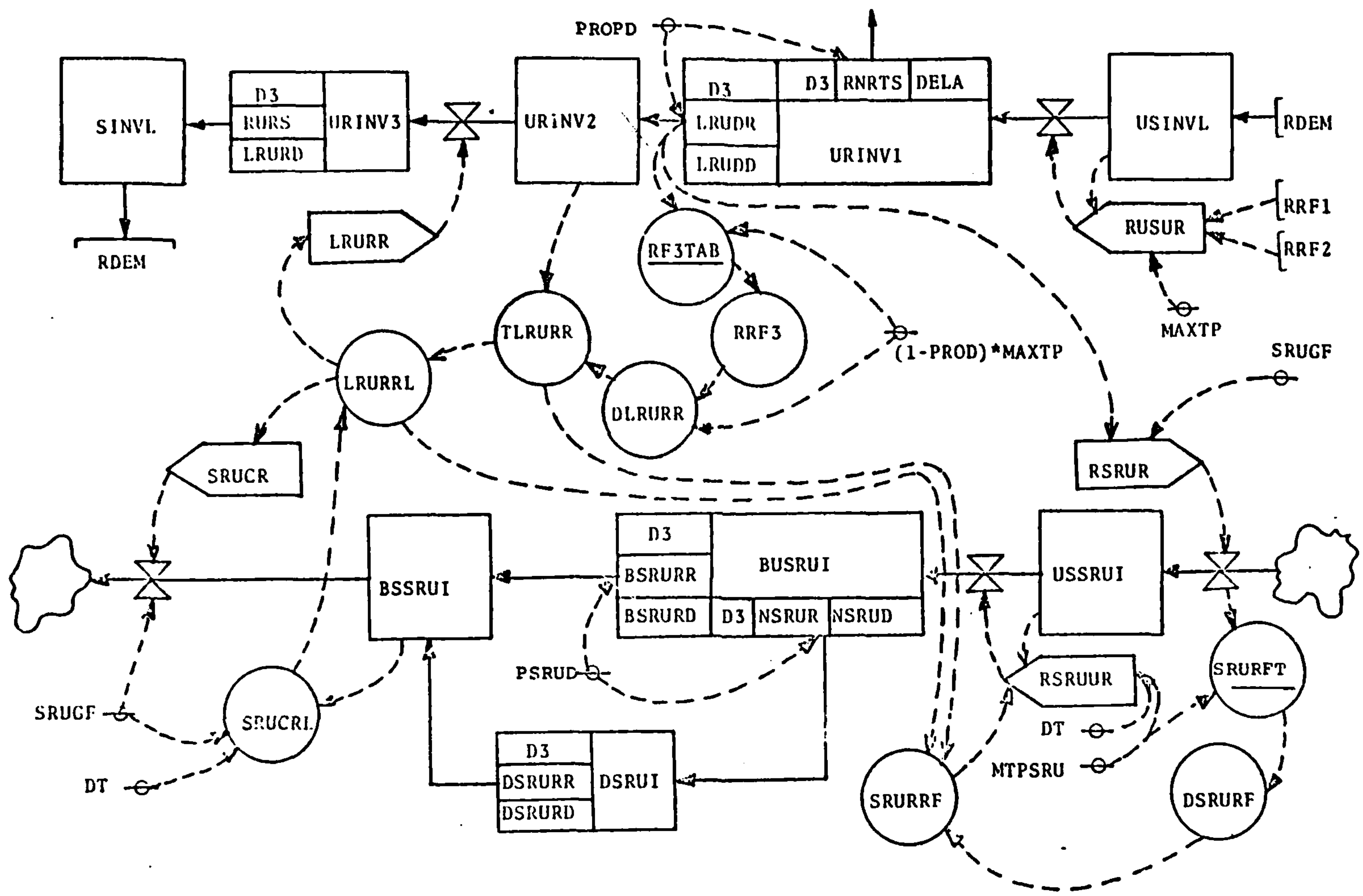
Flow Diagram for Demand Rate Generation Sector



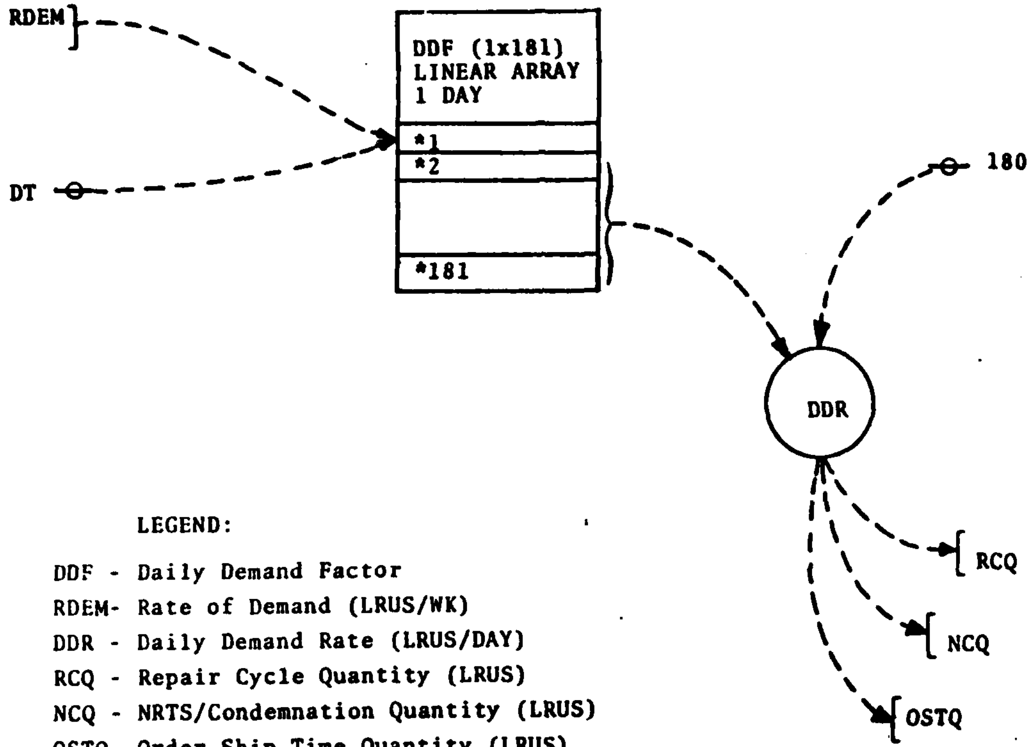
Flow Diagram for Base LRU Repair Process Sector



Flow Diagram for Quality Effects Sector



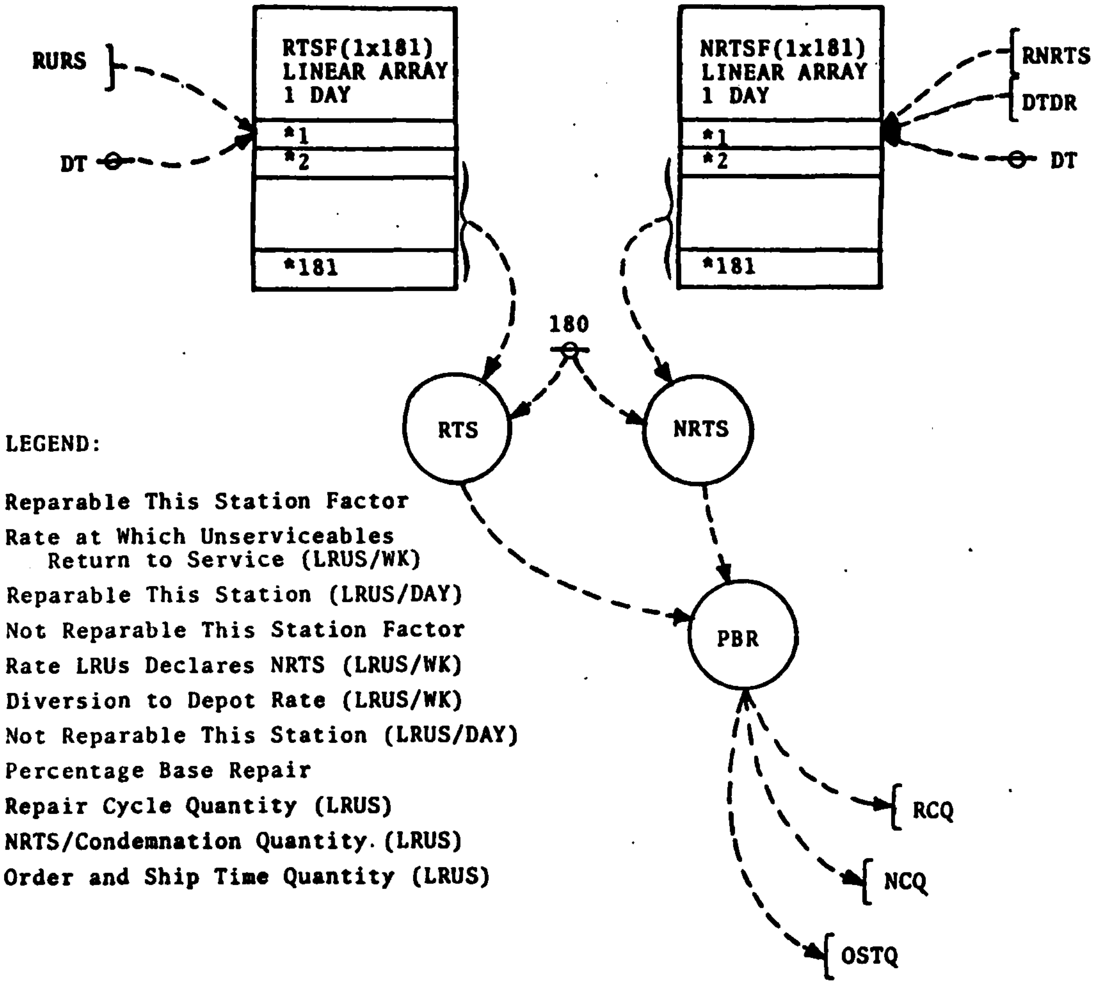
Flow Diagram for Base LRU and SRU Repair Process Sector



LEGEND:

DDF - Daily Demand Factor
RDEM- Rate of Demand (LRUS/WK)
DDR - Daily Demand Rate (LRUS/DAY)
RCQ - Repair Cycle Quantity (LRUS)
NCQ - NRTS/Condemnation Quantity (LRUS)
OSTQ- Order Ship Time Quantity (LRUS)

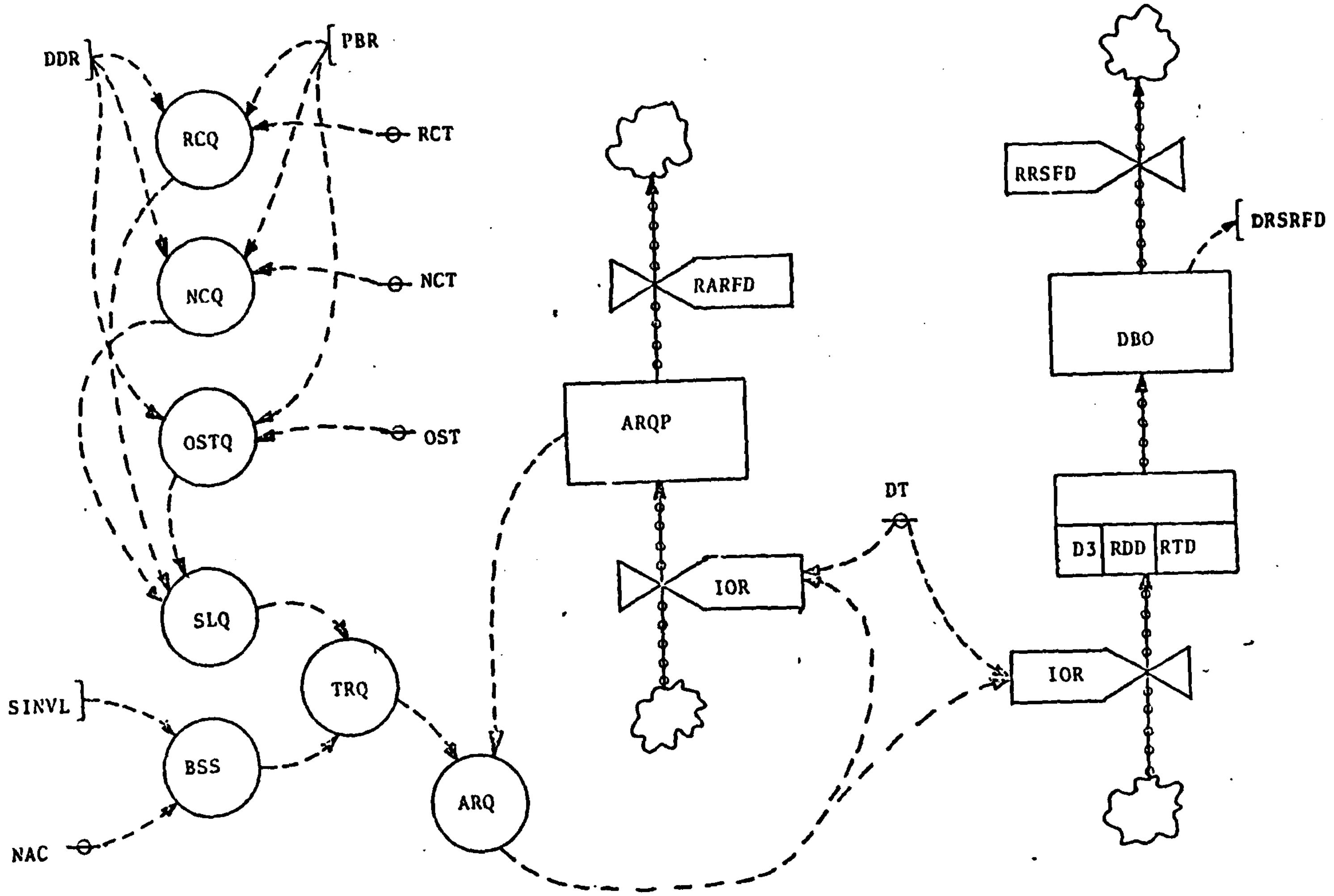
Flow Diagram for Daily Demand Rate Computation



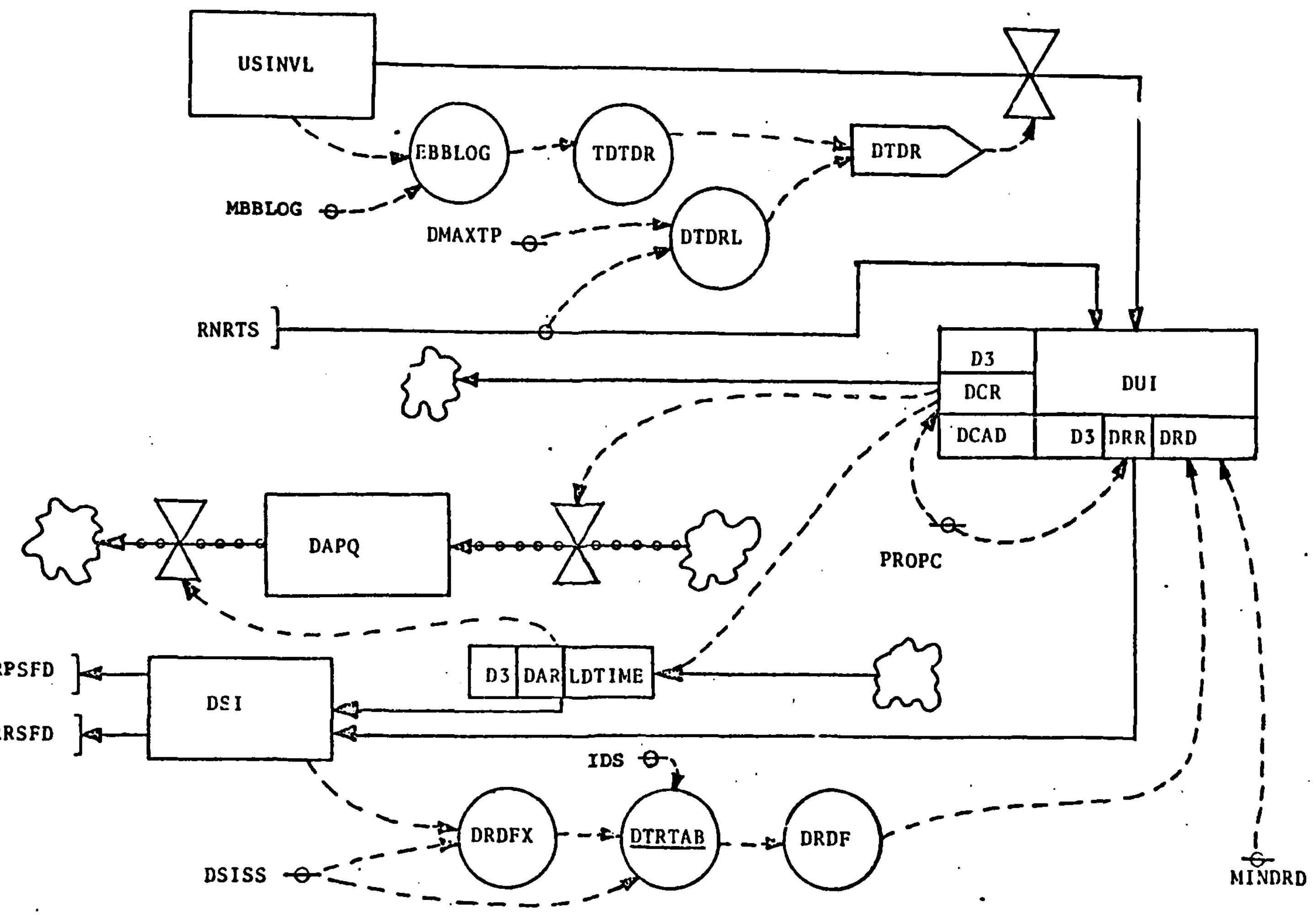
LEGEND:

RTSF - Reparable This Station Factor
RURS - Rate at Which Unserviceables Return to Service (LRUS/WK)
RTS - Reparable This Station (LRUS/DAY)
NRTSF- Not Reparable This Station Factor
RNRTS- Rate LRUs Declares NRTS (LRUS/WK)
DTDR - Diversion to Depot Rate (LRUS/WK)
NRTS - Not Reparable This Station (LRUS/DAY)
PBR - Percentage Base Repair
RCQ - Repair Cycle Quantity (LRUS)
NCQ - NRTS/Condemnation Quantity (LRUS)
OSTQ - Order and Ship Time Quantity (LRUS)

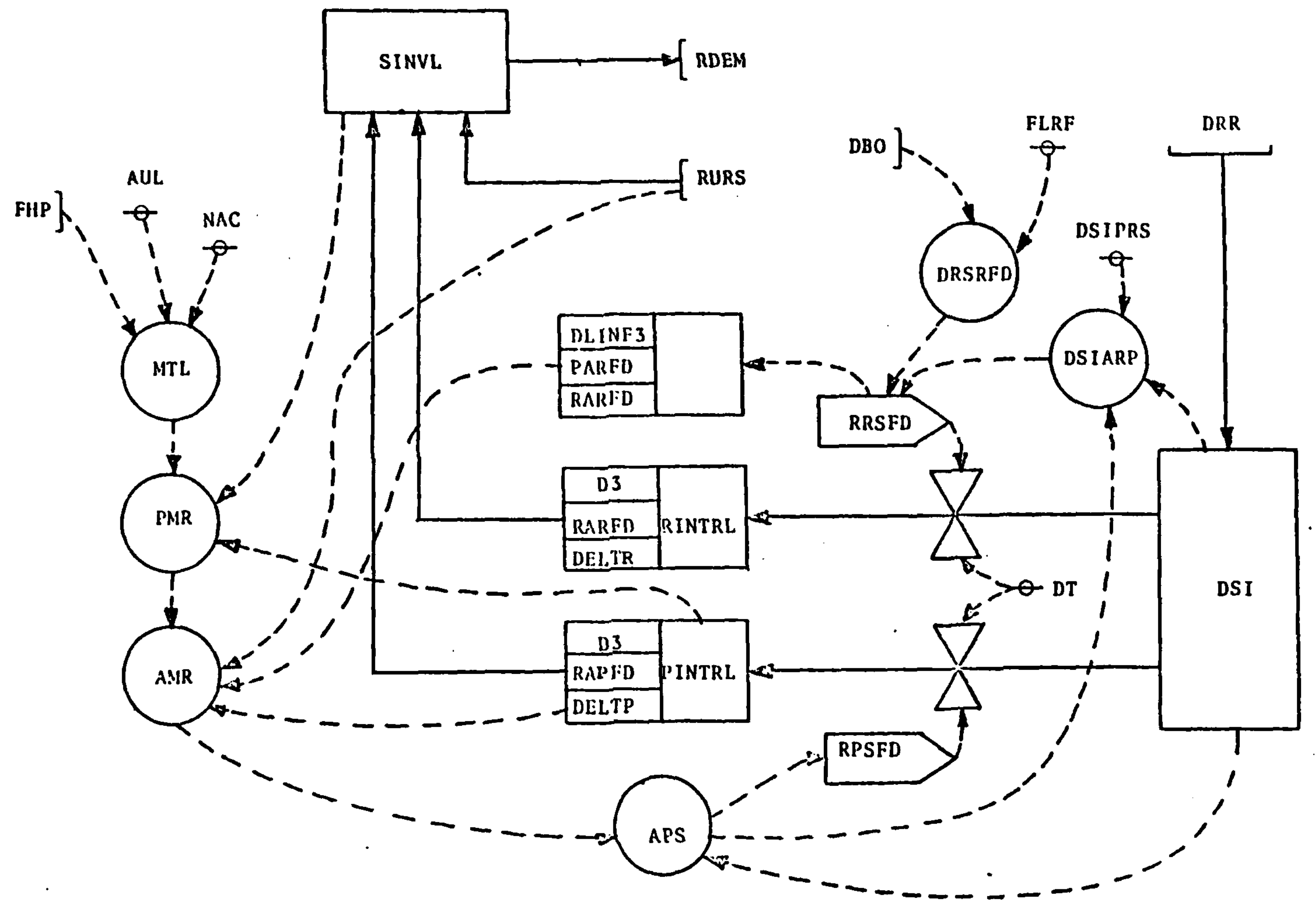
Flow Diagram for Repair Rate Computation



Flow Diagram for Repair Cycle Quantities, Requisitions and Depot Backorders



Flow Diagram for Depot Repair Process Sector



Flow Diagram for Depot Resupply Sector

APPENDIX C

DYNAMO SIMULATION PROGRAM LISTING

```
*    REPARABLE ASSETS SYSTEM POLICY ANALYSIS MODEL

     DEMAND RATE GENERATION SECTOR                                    1-0

     RATE OF EFFORT DETERMINATION

A     SVCAC.K=MIN(SINVL.K,NAC)                                        1-1
C     NAC=72                                                          1-2
A     DAU.K=FHP.K/SVCAC.K                                             1-3
A     RAUF.K=TABHL(AUFTAB,(DAU.K/AUL),0,1,.1)                         1-4
T     AUFTAB=.1/.1/.2/.3/.4/.5/.6/.7/.78/.83/.85                      1-5
C     AUL=25                                                          1-6
A     RAU.K=RAUF.K*AUL                                                1-7
A     ROE.K=FIFZE(0,(RAU.K*SVCAC.K),FHP.K)                            1-8
A     MTBDD.K=NORMRN(250,20)                                          1-9
A     RN.K=NOISE()                                                    1-10
A     MTBDI.K=TABHL(MTITAB,RN.K,-.5,.5,1)                             1-11
T     MTITAB=4/12                                                     1-12
A     IMTBD.K=SAMPLE(MTBDD.K,MTBDI.K,250)                             1-13

     MTBD DETERMINATION

A     MTBD.K=QF1.K*QF2.K*(SMOOTH(IMTBD.K,MTBDSF))                     1-14
C     MTBDSF=5                                                        1-15

     RDEM DETERMINATION

R     RDEM.KL=ROE.K/MTBD.K                                            1-16

         SVCAC - SERVICEABLE AIRCRAFT (UNITS)
         SINVL - SERVICEABLE INVENTORY OF LRUS (LRUS)
         NAC - NUMBER OF AIRCRAFT (UNITS)
         DAU - DESIRED AIRCRAFT UTILIZATION (FLY HR/WK/AIRCRAFT)
         FHP - FLYING HOUR PROGRAM (FLY HR/WK)
         RAUF - REALIZED AIRCRAFT UTILIZATION FACTOR
         AUFTAB - AIRCRAFT UTILIZATION FACTOR TABLE
         AUL - ABSOLUTE UTILIZATION LIMIT (FLY HR/AIRCRAFT/WK)
         RAU - REALIZED AIRCRAFT UTILIZATION (FLY HR/AIRCRAFT/WK)
         ROE - RATE OF EFFORT (FLY HR/WK)
         MTBDD - MTBD DISTRIBUTION (FLY HR)
         RN - RANDOM NUMBER
         MTBDI - MTBD INTERVAL (WKS)
         MTITAB - MEAN TIME INTERVAL TABLE
         IMTBD - INSTANTANEOUS MTBD (FLY HR)
         MTBD - MEAN TIME BETWEEN DEMANDS (FLY HR)
         QF1 - QUALITY FACTOR 1
         QF2 - QUALITY FACTOR 2
         MTBDSF - MTBD SMOOTHING FACTOR (WKS)
         RDEM - RATE OF DEMAND (LRUS/WK)
```

LRU REPAIR PROCESS

```
L       USINVL.K=USINVL.J+DT*(RDEM.JK-RUSUR.JK-DTDR.JK)                        2-1
N       USINVL=0                                                               2-2
A       PDR.K=DLINF3(RDEM.JK,UMRD)                                             2-3
C       UMRD=2                                                                 2-4
A       RRF1.K=TABHL(RF1TAB,(PDR.K/MAXTP),0,1,.1)                              2-5
T       RF1TAB=.5/.5/.53/.58/.65/.73/.82/.91/.97/.98/1.0                       2-6
A       RRF2.K=TABHL(RF2TAB,RAUF.K,0,.7[illegible],.1)                         2-7
T       RF2TAB=.5/.5/.5/.52/.86/.68/.99/1.0                                    2-8
A       DRUSUR.K=MAX(RRF1.K*MAXTP,RRF2.K*MAXTP)                                2-9
R       RUSUR.KL=FIFGE(USINVL.K/DT,DRUSUR.K,DRUSUR.K,USINVL.K/DT)              2-10
C       MAXTP=2                                                                2-11
L       URINV1.K=URINV1.J+DT*(RUSUR.JK-RNRTS.JK-LRUDR.JK)                      2-12
N       URINV1=0                                                               2-13
R       RNRTS.KL=DELAY3(PROPD*RUSUR.JK,DELA)                                   2-14
C       PROPD=0.2                                                              2-15
C       DELA=0.3                                                               2-16
R       LRUDR.KL=DELAY3((1-PROPD)*RUSUR.JK,LRUDD)                              2-17
C       LRUDD=0.4                                                              2-18
L       URINV2.K=URINV2.J+DT*(LRUDR.JK-LRURR.JK)                               2-19
N       URINV2=0                                                               2-20
A       RRF3X.K=LRUDR.JK/((1-PROPD)*MAXTP)                                     2-21
A       RRF3.K=TABHL(RF3TAB,RRF3X.K,0,1,.1)                                    2-22
T       RF3TAB=.625/.625/.[illegible]5/.66/.71/.77/.83/.88/.95/.99/1.0         2-23
NOTE      THE MINIMUM VALUE OF THE ABOVE TABLE IS RELATED TO
          THE MINIMUM VALUE OF THE TABLE FOR RRF1 AS FOLLOWS
             .625=RRF1(MIN)/(1-PROPD)
A       DLRURR.K=RRF3*(1-PROPD)*MAXTP                                          2-24
A       TLRURR.K=FIFGE(URINV2.K/DT,DLRURR.K,DLRURR.K,URINV2.K/DT)              2-25
A       SRUCRL.K=BSSRUI.K/DT                                                   2-26
A       LRURRL.K=FIFGE(SRUCRL.K/SRUGF,TLRURR.K,TLRURR.K,SRUCRL.K/SRUGF)        2-27
R       LRURR.KL=LRURRL.K                                                      2-28
N       LRURR=0                                                                2-29
L       URINV3.K=URINV3.J+DT*(LRURR.JK-RURS.JK)                                2-30
N       URINV3=0                                                               2-31
R       RURS.KL=DELAY3(LRURR.JK,LRURD)                                         2-32
C       LRURD=0.8                                                              2-33
L       SINVL.K=SINVL.J+DT*(RURS.JK+RARFD.JK+RAPFD.JK-RDEM.JK)                 2-34
N       SINVL=BLRU                                                             2-35
C       BLRU=80                                                                2-36
```

USINVL - UNSERVICEABLE LRU INVENTORY (LRUS)
RDEM - RATE OF DEMAND (LRUS/WK)
DTDR - DIVERSION TO DEPOT RATE (LRUS/WK)
PDR - PERCEIVED DEMAND RATE (LRUS/WK)
UMRD - UNIT MAINTENANCE RESPONSE DELAY (WKS)
RRF1 - REPAIR RATE FACTOR 1
RF1TAB - REPAIR RATE FACTOR 1 TABLE
RRF2 - REPAIR RATE FACTOR 2
RF2TAB - REPAIR RATE FACTOR 2 TABLE
RAUF - REALIZED AIRCRAFT UTILIZATION FACTOR
DRUSUR - DESIRED RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
RUSUR - RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
MAXTP - MAXIMUM THROUGHPUT (LRUS/WK)
URINV1 - UNDER REPAIR INVENTORY 1 (LRUS)
RNRTS - RATE LRUS DECLARED NRTS (LRUS/WK)
PROPD - PROPORTION OF LRUS TO DEPOT
DELA - DELAY FOR NRTS ASSESSMENT (WKS)
LRUDR - LRU DIAGNOSIS RATE (LRUS/WK)
LRUDD - LRU DIAGNOSIS DELAY (WKS)

```
URINV2 - UNDER REPAIR INVENTORY 2 (LRUS AWAITING SRUS)
RRF3X - REPAIR RATE FACTOR 3 INDEX
RRF3 - REPAIR RATE FACTOR 3
RF3TAB - REPAIR RATE FACTOR 3 TABLE
DLRURR - DESIRED LRU REPAIR RATE (LRUS/WK)
TLRURR - TRIAL LRU REPAIR RATE (LRUS/WK)
SRUCRL - SRU CONSUMPTION RATE LIMIT (SRUS/WK)
LRURRL - LRU REPAIR RATE LIMIT (LRUS/WK)
LRURR - LRU REPAIR RATE (LRUS/WK)
URINV3 - UNDER REPAIR INVENTORY 3 (LRUS)
RURS - RATE AT WHICH UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)
LRURD - LRU REPAIR DELAY (WKS)
SINVL - SERVICEABLE INVENTORY OF LRUS (LRUS)
RARFD - RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
RAPFD - RATE OF ARRIVAL OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
BLRU - BASE LRU INVENTORY (LRUS)
```

SRU REPAIR PROCESS

```
R    RSRUR.KL=LRUDR.JK*SRUGF                                           2-37
C    SRUGF=2.5                                                         2-38
L    USSRUI.K=USSRUI.J+DT*(RSRUR.JK-RSRUUR.JK)                         2-39
N    USSRUI=0                                                          2-40
A    SRURFX.K=RSRUR.JK/MTPSRU                                          2-41
C    MTPSRU=3                                                          2-42
A    DSRURF.K=TABHL(SRURFT,SRURFX.K,0,1,.1)                            2-43
T    SRURFT=.5/.5/.53/.58/.65/.73/.82/.91/.97/.98/1.0                  2-44
A    SRURRF.K=FIFZE(DSRURF.K,1,TLRURR.K-LRURRL.K)                      2-45
R    RSRUUR.KL=FIFGE(USSRUI.K/DT,SRURRF.K*MTPSRU,SRURRF.K*MTPSRU,      2-46
X       USSRUI.K/DT)                                                   2-47
L    BUSRUI.K=BUSRUI.J+DT*(RSRUUR.JK-BSRURR.JK-NSRUR.JK)               2-48
N    BUSRUI=0                                                          2-49
R    NSRUR.KL=DELAY3(PSRUD*RSRUUR.JK,NSRUD)                            2-50
C    PSRUD=0.2                                                         2-51
C    NSRUD=0.5                                                         2-52
L    DSRUI.K=DSRUI.J+DT*(NSRUR.JK-DSRURR.JK)                           2-53
N    DSRUI=0                                                           2-54
R    DSRURR.KL=DELAY3(NSRUR.JK,DSRURD)                                 2-55
C    DSRURD=6                                                          2-56
R    BSRURR.KL=DELAY3((1-PSRUD)*RSRUUR.JK,BSRURD)                      2-57
C    BSRURD=2                                                          2-58
L    BSSRUI.K=BSSRUI.J+DT*(BSRURR.JK+DSRURR.JK-SRUCR.JK)               2-59
N    BSSRUI=BSRU                                                       2-60
C    BSRU=15                                                           2-61
R    SRUCR.KL=LRURRL.K*SRUGF                                           2-62
```

```
RSRUR - REPAIRABLE SRU RATE (SRU/WK)
SRUGF - SRU GENERATION FACTOR (SRUS/LRU)
USSRUI - UNSERVICEABLE SRU INVENTORY (SRUS)
SRURFX - SRU REPAIR FACTOR INDEX
MTPSRU - MAXIMUM THROUGHPUT OF SRUS (SRUS/WK)
DSRURF - DESIRED SRU REPAIR FACTOR
SRURFT - SRU REPAIR FACTOR TABLE
SRURRF - SRU REPAIR RATE FACTOR
RSRUUR - RATE SRUS GO UNDER REPAIR (SRUS/WK)
BUSRUI - BASE UNSERVICEABLE SRU INVENTORY (SRUS)
NSRUR - RATE SRUS DECLARED NRTS (SRUS/WK)
PSRUD - PROPORTION OF SRUS TO DEPOT
NSRUD - NRTS SRU ASSESSMENT DELAY (WKS)
DSRUI - DEPOT SRU INVENTORY (SRUS)
DSRURR - DEPOT SRU REPAIR RATE (SRUS/WK)
DSRURD - DEPOT SRU REPAIR DELAY (WKS)
BSRURR - BASE SRU REPAIR RATE (SRUS/WK)
BSRURD - BASE SRU REPAIR DELAY (WKS)
BSSRUI - BASE SERVICEABLE SRU INVENTORY (SRUS)
BSRU - BASE SRU STOCK (SRUS)
SRUCR - SRU CONSUMPTION RATE (SRUS/WK)
```

```
      QUALITY EFFECTS SECTOR                                          3-0

A      QF1.K=TABHL(QTAB1,RAU.K/21,.25,.5,1,.5)                        3-1
T      QTAB1=1/.8                                                     3-2
N      QF1=1                                                          3-3

R      QFR1.KL=FIFZE(RUSUR.JK,0,RUSUR.JK-MAXTP)                       3-4
R      QFR2.KL=DELAY3(QFR1.JK,QRTF)                                   3-5
C      QRTF=10                                                        3-6
A      QFX.K=QFR2.JK/MAXTP                                            3-7
A      QF2.K=TABHL(QTAB2,QFX.K,0,1,1)                                 3-8
T      QTAB2=1.0/0.9                                                  3-9
N      QF2=1                                                          3-10

          QF1 - QUALITY FACTOR 1
          RAU - REALIZED AIRCRAFT UTILIZATION (FLY HR/AIRCRAFT/WK)
          QTAB1 - QUALITY FACTOR TABLE 1
          QFR1 - QUALITY FACTOR RATE 1
          RUSUR - RATE UNSERVICEABLES GO UNDER REPAIR (LRUS/WK)
          MAXTP - MAXIMUM THROUGHPUT  (LRUS/WK)
          QFR2 - QUALITY FACTOR RATE 2
          QRTF - QUALITY RATE TIME FACTOR (WKS)
          QFX - QUALITY FACTOR INDEX
          QF2 - QUALITY FACTOR 2
          QTAB2 - QUALITY FACTOR TABLE 2


      ROUTINE REQUISITION PROCESS SECTOR                              4-0

      LRU DAILY DEMAND RATE COMPUTATION

FOR    I=1,181                                                        4-1
L      DDF.K(I)=DDF.J(I)+DT*RDEM.JK                                   4-2
N      DDF(I)=0.2                                                     4-3
A      DDR.K=SUMV(DDF.K,2,181)/180                                    4-4
S      LDD.K=SHIFTL(DDF.K,.143)                                       4-5

          DDF - DAILY DEMAND FACTOR
          RDEM - RATE OF DEMAND (LRUS/WK)
          DDR - DAILY DEMAND RATE (LRUS/DAY)
          LDD - DAILY DEMAND FACTOR ARRAY SHIFT DUMMY VARIABLE

      BASE REPAIR RATE COMPUTATION

L      RTSF.K(1)=RTSF.J(1)+DT*RURS.JK                                 4-6
N      RTSF(1)=0.8                                                    4-7
A      RTS.K=SUMV(RTSF.K,2,181)/180                                   4-8
S      LRTS.K=SHIFTL(RTSF.K,.143)                                     4-9
L      NRTSF.K(1)=NRTSF.J(1)+(DT*(RNRTS.JK+DTDR.JK))                  4-10
N      NRTSF(1)=0.2                                                   4-11
A      NRTS.K=SUMV(NRTSF.K,2,181)/180                                 4-12
S      LNRTS.K=SHIFTL(NRTSF.K,.143)                                   4-13
A      PBR.K=RTS.K/(RTS.K+NRTS.K)                                     4-14

          RTSF - REPARABLE THIS STATION FACTOR
          RURS - RATE AT WHICH UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)
          RTS - REPARABLE THIS STATION (LRUS/DAY)
          LRTS - RTS FACTOR ARRAY SHIFT DUMMY VARIABLE
          NRTSF - NOT REPARABLE THIS STATION FACTOR
          RNRTS - RATE LRUS DECLARED NRTS (LRUS/WK)
          DTDR - DIVERSION TO DEPOT RATE (LRUS/WK)
          NRTS - NOT REPARABLE THIS STATION (LRUS/DAY)
          LNRTS - NRTS FACTOR ARRAY SHIFT DUMMY VARIABLE
          PBR - PERCENTAGE BASE REPAIR
```

REPAIR CYCLE QUANTITIES

```
A    RCQ.K=(DDR.K*PBR.K*RCT)                                   4-15
C    RCT=7.5                  - IN DAYS                        4-16
A    NCQ.K=DDR.K*(1-PBR.K)*NCT                                 4-17
C    NCT=2.5                  - IN DAYS                        4-18
A    OSTQ.K=DDR.K*(1-PBR.K)*OST                                4-19
C    OST=6.0                  - IN DAYS                        4-20
A    SLQ.K=SQRT(3*(RCQ.K+NCQ.K+OSTQ.K))                        4-21

        RCQ - REPAIR CYCLE QUANTITY (LRUS)
        DDR - DAILY DEMAND RATE (LRUS/DAY)
        PBR - PERCENTAGE BASE REPAIR
        RCT - REPAIR CYCLE TIME (DAYS)
        NCQ - NRTS/CONDEMNED QUANTITY (LRUS)
        NCT - NRTS/CONDEMNATION ASSESSMENT TIME (DAYS)
        OSTQ - ORDER AND SHIP TIME QUANTITY (LRUS)
        OST - ORDER AND SHIP TIME (DAYS)
       SLQ - SAFETY LEVEL QUANTITY (LRUS)
```

DEMAND COMPUTATION

```
A    BSS.K=MAX(0,(SINVL.K-NAC))                                4-22
A    TRQ.K=MAX(0,(SLQ.K-BSS.K))                                4-23
L    ARQP.K=ARQP.J+DT*(IOR.JK-RARFD.JK)                        4-24
N    ARQP=0                                                    4-25
A    ARQ.K=MAX(0,(TRQ.K-ARQP.K))                               4-26
R    IOR.KL=ARQ.K/DT                                           4-27

        BSS - BASE SERVICEABLE STOCK (LRUS)
        SINVL - SERVICEABLE INVENTORY OF LRUS (LRUS)
        NAC - NUMBER OF AIRCRAFT (UNITS)
        TRQ - TRIAL REQUISITION QUANTITY (LRUS)
       SLQ - SAFETY LEVEL QUANTITY (LRUS)
        ARQP - ACTUAL REQUISITIONS PLACED WITH DEPOT (ORDERS)
        RARFD - RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        ARQ - ACTUAL REQUISITION QUANTITY (LRUS)
        IOR - INSTANTANEOUS ORDER RATE (LRU ORDERS/WK)
```

BACKORDER ACCUMULATION

```
R    RDD.KL=DELAY3(IOR.JK,RTD)                                 4-28
C    RTD=.4                                                    4-29
L    DBO.K=DBO.J+DT*(RDD.JK-RRSFD.JK)                          4-30
N    DBO=0                                                     4-31

        RDD - REQUISITION DELAY TO DEPOT (ORDERS/WK)
        IOR - INSTANTANEOUS ORDER RATE (LRU ORDERS/WK)
        RTD - REQUISITION TRANSMISSION DELAY (WKS)
        DBO - DEPOT BACK ORDERS (ORDERS)
        RRSFD - RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
```

```
     DEPOT REPAIR SECTOR                                                   5-0

A    EBBLOG.K=MAX(USINVL.K-MBBLOG,0)                                       5-1
C    MBBLOG=13     (MAXTP*AVG DEPOT TAT OF 6.5 WKS)                        5-2
A    TDTDR.K=EBBLOG.K/DT                                                   5-3
A    DTDRL.K=DMAXTP-RNRTS.JK                                               5-4
C    DMAXTP=.8      (2*PROPD*MAXTP)                                        5-5
R    DTDR.KL=FIFGE(DTDRL.K,TDTDR.K,TDTDR.K,DTDRL.K)                        5-6
L    DUI.K=DUI.J+DT*(RNRTS.JK+DTDR.JK-DCR.JK-DRR.JK)                       5-7
N    DUI=0                                                                 5-8
R    DRR.KL=DELAY3((1-PROPC)*(RNRTS.JK+DTDR.JK),DRD.K)                     5-9
C    PROPC=.001                                                            5-10
A    DRDFX.K=DSI.K/DSISS                                                   5-11
A    DRDF.K=TABHL(DRDTAB,DRDFX.K,1.1,IDS/DSISS,(IDS/DSISS)-1.1)            5-12
T    DRDTAB=1/3                                                            5-13
C    IDS=10                                                                5-14
C    DSISS=2         (2*DSIMRS)                                            5-15
A    DRD.K=DRDF.K*MINDRD                                                   5-16
C    MINDRD=2                                                              5-17
R    DCR.KL=DELAY3(PROPC*(RNRTS.JK+DTDR.JK),DCAD)                          5-18
C    DCAD=0.3                                                              5-19
L    DAPQ.K=DAPQ.J+DT*(DCR.JK-DAR.JK)                                      5-20
N    DAPQ=0                                                                5-21
R    DAR.KL=DELAY3(DCR.JK,LDTIME)                                          5-22
C    LDTIME=80                                                             5-23
L    DSI.K=DSI.J+DT*(DRR.JK-RRSFD.JK-RPSFD.JK+DAR.JK)                      5-24
N    DSI=IDS                                                               5-25

        EBBLOG - EXCESS BASE MAINTENANCE BACKLOG (LRUS)
        USINVL - UNSERVICEABLE LRU INVENTORY (LRUS)
        MBBLOG - MAXIMUM BASE MAINTENANCE BACKLOG (LRUS)
        TDTDR - TRIAL DIVERSION TO DEPOT RATE (LRUS/WK)
        DTDRL - DIVERSION TO DEPOT RATE LIMIT (LRUS/WK)
        DMAXTP - DEPOT MAXIMUM REPAIR THROUGHPUT (LRUS/WK)
        RNRTS - RATE LRUS DECLARED NRTS (LRUS/WK)
        DTDR - DIVERSION TO DEPOT RATE (LRUS/WK)
        DUI - DEPOT UNSERVICEABLE INVENTORY (LRUS)
        DRR - DEPOT REPAIR RATE (LRUS/WK)
        PROPC - PROPORTION CONDEMNED
        DRDFX - DEPOT REPAIR DELAY FACTOR INDEX
        DRDF - DEPOT REPAIR DELAY FACTOR
        DRDTAB - DEPOT REPAIR DELAY TABLE
        IDS - INITIAL DEPOT STOCK (LRUS)
        DSISS - DEPOT SERVICEABLE INVENTORY SAFETY STOCK (LRUS)
        DRD - DEPOT REPAIR DELAY (WKS)
        MINDRD - MINIMUM DEPOT REPAIR DEALY (WKS)
        DCR - DEPOT CONDEMNATION RATE (LRUS/WK)
        DAPQ - DEPOT ACQUISITION PIPELINE QUANTITY (LRUS)
        DCAD - DEPOT CONDEMNATION ASSESSMENT DELAY (WKS)
        DAR - DEPOT ACQUISITION RATE (LRUS/WK)
        LDTIME - ACQUISITION LEAD TIME (WKS)
        DSI - DEPOT SERVICEABLE INVENTORY (LRUS)
        RRSFD - RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        RPSFD - RATE OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
```

```
DEPOT RESUPPLY SECTOR                                                6-0

MICAP DETERMINATION AND DEPOT RESPONSE

A     MTL.K=MIN(FHP.K/(0.7*AUL),NAC)                                 6-1
A     PMR.K=MAX((MTL.K-(PINTRL.K+SINVL.K)),0)                        6-2
A     PARFD.K=DLINF3(RRSFD.JK,RARPD)                                 6-3
C     RARPD=3                                                        6-4
A     AMR.K=MAX((PMR.K-RURS.JK*DELTP-PARFD.K*DELTP),0)               6-5
N     AMR=0                                                          6-6
A     AMS.K=MIN(AMR.K,DSI.K)                                         6-7
R     RPSFD.KL=AMS.K/DT                                              6-8
L     PINTRL.K=PINTRL.J+DT*(RPSFD.JK-RAPFD.JK)                       6-9
N     PINTRL=0                                                       6-10
R     RAPFD.KL=DELAY3(RPSFD.JK,DELTP)                                6-11
C     DELTP=0.5                                                      6-12

        MTL - MICAP THRESHOLD LEVE (LRUS)
        FHP - FLYING HOUR PROGRAM (FLY HR/WK)
        AUL - ABSOLUTE UTILIZATION LIMIT (FLY HR/AIRCRAFT/WK)
        NAC - NUMBER OF AIRCRAFT (UNITS)
        PMR - POTENTIAL MICAP REQUIREMENTS (LRUS)
        SINVL - SERVICEABLE INVENTORY OF LRUS (LRUS)
        PARFD - PERCEIVED ARRIVAL RATE ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        RRSFD - RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        RARPD - ROUTINE ARRIVAL RATE PERCEPTION DELAY (WKS)
        AMR - ACTUAL MICAP REQUIREMENTS (LRUS)
        RURS - RATE AT WHICH UNSERVICEABLES RETURN TO SERVICE (LRUS/WK)
        AMS - ACTUAL MICAP SHIPMENTS (LRUS)
        DSI - DEPOT SERVICEABLE INVENTORY (LRUS)
        RPSFD - RATE OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
        PINTRL - PRIORITY SHIPMENTS INTRANSIT LEVEL (LRUS)
        RAPFD - RATE OF ARRIVAL OF PRIORITY SHIPMENTS FROM DEPOT (LRUS/WK)
        DELTP - PRIORITY TRANSPORTATION PIPELINE DELAY (WKS)

ROUTINE REQUISITIONS RESPONSE

A     DSIARP.K=MAX((DSI.K-DSIMRS-AMS.K),0)                           6-13
C     DSIMRS=1                                                       6-14
A     DRSRFD.K=DBO.K/FLRF                                            6-15
C     FLRF=0.4                                                       6-16
R     RRSFD.KL=FIFGE(DSIARP.K/DT,DRSRFD.K,DRSRFD.K,DSIARP.K/DT)      6-17
L     RINTRL.K=RINTRL.J+DT*(RRSFD.JK-RARFD.JK)                       6-18
N     RINTRL=0                                                       6-19
R     RARFD.KL=DELAY3(RRSFD.JK,DELTR)                                6-20
C     DELTR=2.0                                                      6-21

        DSIARP - DEPOT SERVICEABLE INVENTORY AVAILABLE TO THE ROUTINE PIPELINE
                                                                     (LRUS)
        DSI - DEPOT SERVICEABLE INVENTORY (LRUS)
        AMS - ACTUAL MICAP SHIPMENTS (LRUS)
        DSIMRS - DEPOT SERVICEABLE INVENTORY MICAP RESERVE STOCK (LRUS)
        DRSRFD - DESIRED ROUTINE SHIPMENT RATE FROM DEPOT (LRUS/WK)
        DBO - DEPOT BACK ORDERS (ORDERS)
        FLRF - FILL RATE FACTOR (WKS)
        RRSFD - RATE OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        RINTRL - ROUTINE INTRANSIT PIPELINE LEVEL (LRUS)
        RARFD - RATE OF ARRIVAL OF ROUTINE SHIPMENTS FROM DEPOT (LRUS/WK)
        DELTR - ROUTINE TRANSPORTATION DELAY (WKS)
```

```
     SUPPLEMENTARIES

S      ATBA.K=SINVL.K+USINVL.K+URINV1.K+URINV2.K+URINV3.K+
X         RINTRL.K+PINTRL.K
S      PTBA.K=NAC+BSS.K+RCQ.K+NCQ.K+OSTQ.K+ARQP.K+PINTRL.K
S      PWDR.K=DDR.K*7
S      TRTD.K=(RNRTS.JK+DTDR.JK)
S      BMXA.K=USINVL.K+URINV1+URINV2+URINV3

          ATBA - ACTUAL TOTAL BASE ASSETS (LRUS)
          PTBA - PERCEIVED TOTAL BASE ASSETS (LRUS)
          PWDR - PERCEIVED WEEKLY DEMAND RATE (LRUS/WK)
          TRTD - TOTAL RATE AT WHICH UNSERVICEABLES ARE SENT TO DEPOT (LRUS/WK)
          BMXA - BASE MAINTENANCE WORKLOAD (LRUS)

     INPUT FUNCTION---FLYING HOUR PROGRAM

A      FHP.K=STEP(300,0)+STEP(600,10)-STEP(900,30)+STEP(400,60)  TEST

     DIRECTIONS

PRINT     1)DAU,RAUF,RAU,ROE,MTBD,RDEM,*,QF1,QF2,*,RRF1,RRF2/
X         2)USINVL,RUSUR,URINV1,LRUDR,RNRTS,URINV2,*,RRF3/
X         3)DLRURR,TLRURR,SRUCRL,LRURR,URINV3,RURS,SINVL,*,SRURRF/
X         4)RSRUR,USSRUI,RSRUUR,BUSRUI,DSRURR,BSRURR,BSSRUI,SRUCR/
X         5)DDR,PBR,SLQ,BSS,ARQP,APQ,IOR,DBO/
X         6)RNRTS,DTDR,DUI,DRD,DRR,DCR,DAPQ,DAR,DSI/
X         7)MTL,PMR,AMR,AMS,RPSFD,PINTRL,RAPFD/
X         8)DBO,OSIARP,DRSRFD,RRSFD,RINTRL,RARFD/
X         9)ATBA,*,PTBA,*,PWDR,*,BMXA,*,TRTD/
X         10)SINVL,SVCAC,*,FHP,RAU,ROE,*,USINVL,URINV2/
X         11)RDEM,RUSUR,LRURR,*,TRTD,RARFD,RAPFD
PLOT      URINV2=2,SVCAC=A/FHP=F,ROE=E/BSS=B,SLQ=Q/MTBD=M/
X           RARFD=R,RAPFD=P/DDR=D
PLOT      SINVL=S,BMXA=U/ROE=E/RDEM=D/RUSUR=1,RURS=2,TRTD=3,
X           DRR=4,RARFD=5,RAPFD=6
PLOT      ROE=E/MTBD=M/SINVL=S,USINVL=U,URINV2=2/
X           DDR=D/PWDR=W,RDEM=T/ATBA=A,PTBA=P

SPEC   DT=.05/LENGTH=200/PLTPER=1/PRTPER=1

RUN
```

APPENDIX D

PERSONAL INTERVIEWS

Anderson, Joyce. Requirements Determination Division, HQ AFLC/LORR, Wright-Patterson AFB OH. Personal interview. 22 April 1981.

Badalamente, Lieutenant Colonel Richard V. Associate Professor of Logistics Management, AFIT/LSM, Wright-Patterson AFB OH. Personal interviews. 9-10 April 1981.

Barnes, Warren S. Associate Professor of Logistics Management, AFIT/LSM, Wright-Patterson AFB OH. Personal interview. 3 April 1981.

Butler, Richard. Chief, Provisioning and Cataloging Division, HQ AFLC/LOLC, Wright-Patterson AFB OH. Personal interview. 17 April 1981.

Goecke, Robert. Provisioning and Cataloging Divsion, HQ AFLC/LOLCP, Wright-Patterson AFB OH. Personal interview. 17 April 1981.

Lawson, Diane. Chief, Reports and Analysis Branch, HQ AFLC/LOR, Wright-Patterson AFB OH. Personal interview. 3 October 1980.

Masters, Major James M. Assistant Professor of Logistics Management, AFIT/LSB, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 7 January 1981 to 8 May 1981.

Papalios, Gust P. Chief, Functional System Division, HQ AFLC/XRBF, Wright-Patterson AFB OH. Personal interview. 6 April 1981.

Persuitti, Victor. Chief, Requirements Determination Branch, HQ AFLC/XRX, Wright-Patterson AFB OH. Personal interview. 9 October 1980.

Zimmerman, Steven. Provisioning and Cataloging Division, HQ AFLC/LOLCP, Wright-Patterson AFB OH. Personal interview. 17 April 1981.

APPENDIX E

RESULTS FOR EXPERIMENTAL RUN 1

(TEST FLYING HOUR PROGRAM INPUT FUNCTION)

Format Conventions

The output of this appendix has been prepared using the following format conventions.

Graphical Output

1. Each variable is represented by an identifying character. A legend relating variable names with their plotting character appears at the head of the output.

2. Multiple scales are used. The scale for a particular variable (or variables) being designated with the plotting character for the variable.

3. The vertical scale is TIME (in weeks).

4. Variables with coincident plot positions are represented by the character for the variable which appears first in the legend for plotting characters. The groups of coincident variables are listed down the right side of the output in line with their coincident plot position.

Tabular Output

1. The names of the tabulated quantities are printed at the beginning of the output.

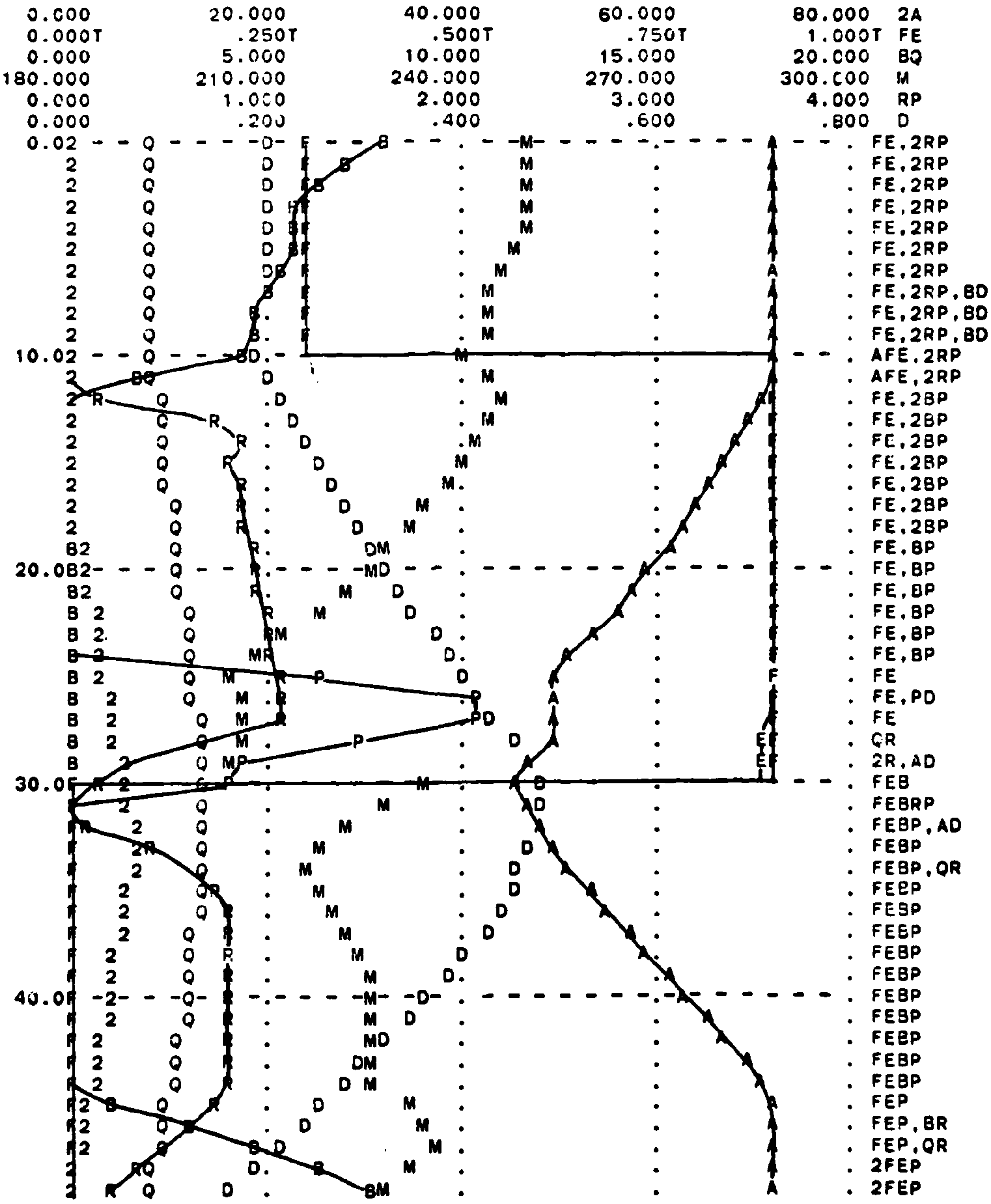
2. Scale factors for the printed quantities are given under the names for the tabulated quantities. The scale factors follow the normal scientific notation convention, e.g., E - 03 = $*10^3$ (or move the decimal point three places to the left of

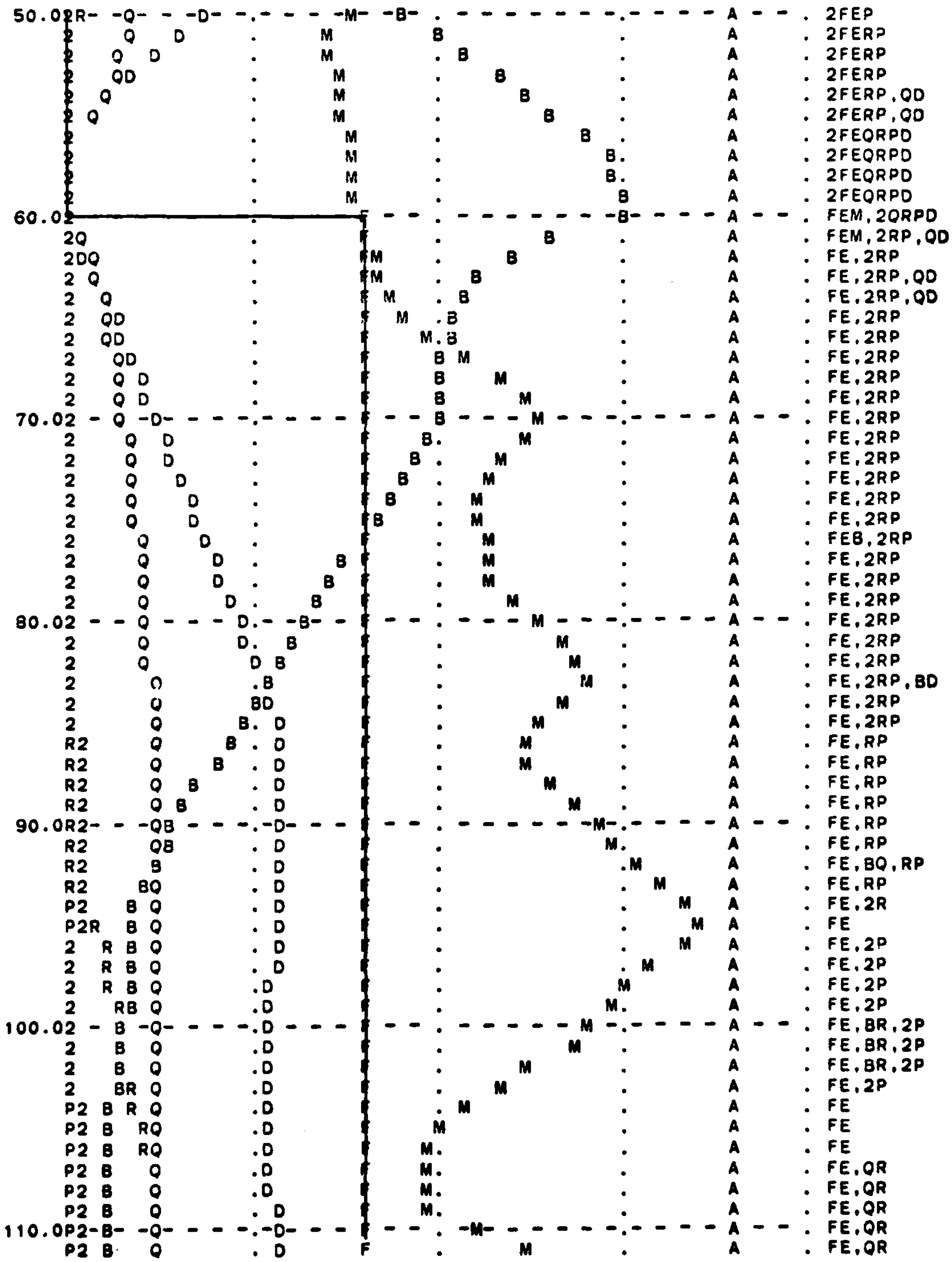
the printed position).

3. The two columns on the right contain a summary of the more significant quantities.

REPARABLE ASSETS SYSTEM POLICY ANALYSIS MODEL

URINV2=2 SVCAC=A FHP=F ROE=E BSS=B SLQ=Q MTBD=M RARFD=R
RAPFD=P DDR=D





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      P2 B    Q      . D       F       .         M      .        A     . FE,QR
      P2   B RQ      . D       F       .            M   .        A     . FE
      P2   B RQ      . D       F       .            M   .        A     . FE
      P2   BR Q      . D       F       .        M       .        A     . FE
      P2   BR Q      . D       F       .    M           .        A     . FE
      P2   BR Q      . D       F       . M              .        A     . FE
      P 2B   RQ      . D       F       .M               .        A     . FE
      P 2B   RQ      . D       F    M  .                .        A     . FE
120.0P 2B- -Q- - - -.-D- - - FM- - . - - - - - - - - -.- - - - - A - - - . FE,QR
      P 2    Q       . D   M F         .                .        A     . FE,2B,QR
      P 2    QR      . D  M  F         .                .        A     . FE,2B
      P 2    QR      . D    MF         .                .        A     . FE,2B
      P 2    Q R     . D     FM        .                .        A     . FE,2B
      P B2   Q R     .  D    F  M      .                .        A     . FE
      P B2   QR      .  D    F    M    .                .        A     . FE
      P  2   QR      .  D    F  M      .                .        A     . FE,2B
      P  2   QR      .  D    F M       .                .        A     . FE,2B
      P  2   QR      .  D    F M       .                .        A     . FE,2B
130.0P -2- -QR - - -.- D - - FM- - . - - - - - - - - -.- - - - - A - - - . FE,2B
      P B2   QR      .  D    FM        .                .        A     . FE
      P B2   QR      .  D    F M       .                .        A     . FE
      P B 2  QR      .  D    F M       .                .        A     . FE
      P  B2  QR      .  D    F M       .                .        A     . FE
      P  B2  QR      .  D    F  M      .                .        A     . FE
      P  B2  QR      .  D    F     M.                   .        A     . FE
      P  B2  QR      .  D    F       .M                 .        A     . FE
      P  B2  QR      .  D    F       .M                 .        A     . FE,QR
      P  B2  Q       .  D    F       . M                .        A     . FE,QR
      P  B2  Q       .  D    F       .    M             .        A     . FE,QR
140.0P -B2 -Q- - - -.- D - - F - - . - M - - - - - - -.- - - - - A - - - . FE,QR
      P  B2  Q       .  D    F       .  M               .        A     . FE,QR
      P    2 RQ      .  D    F       .  M               .        A     . FE,2B
      P   B 2RQ      .  D    F       . M                .        A     . FE
      P   B 2RQ      .  D    F       . M                .        A     . FE
      P   B 2RQ      .  D    F       .M                 .        A     . FE
      P   B 2 Q      .  D    F       M                  .        A     . FE,QR
      P   B 2 Q      .  D    F     M.                   .        A     . FE,QR
      P   B 2 Q      .  D    F    M .                   .        A     . FE,QR
      P   B 2 Q      .  D    F    M .                   .        A     . FE,QR
150.0P -B-2-Q- - - -.- D - - F - M . - - - - - - - - -.- - - - - A - - - . FE,QR
      P   B 2 Q      .  D    F  M   .                   .        A     . FE,QR
      P   B 2 Q      .  D    F  M   .                   .        A     . FE,QR
      P   B   2QR    .  D    F    M .                   .        A     . FE
      P   B   2QR    .  D    F       .M                 .        A     . FE
      P   B   2Q     .  D    F       . M                .        A     . FE,QR
      P   B   2Q     .  D    F       .    M             .        A     . FE,QR
      P   B   2Q     .  D    F       .     M            .        A     . FE,QR
      P     B 2Q     .  D    F       .       M          .        A     . FE,2R
      P     B 2Q     .  D    F       .       M          .        A     . FE,2R
160.0P - B 2Q- - - -.- D - - F - - . - - M - - - - - -.- - - - - A - - - . FE,2R
      P     B 2Q     .  D    F       .       M          .        A     . FE,2R
      P     B 2Q     .  D    F       .       M          .        A     . FE,2R
      P     B 2Q     .  D    F       .     M            .        A     . FE,2R
      P     B 2Q     .  D    F       .     M            .        A     . FE,2R
      P     B 2Q     .  D    F       .    M             .        A     . FE,2R
      P     B 2Q     .  D    F       .    M             .        A     . FE,2R
      P   B   R2     .  D    F       .      M           .        A     . FE,2Q
      P     B R2     .  D    F       .       M          .        A     . FE,2Q
      P     B R2     .  D    F       .         M        .        A     . FE,2Q
170.0P - B R2- - - -.- D - - F - - . - - -M- - - - - -.- - - - - A - - - . FE,2Q
      P     B R2     . D     F       .      M           .        A     . FE,2Q
      P     B R2     . D     F       .   M              .        A     . FE,2Q
      P   B   R2     . D     F       .M                 .        A     . FE,2Q
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         P    B 2Q          .  D      F       .      M            .            A      . FE,2R
         P    B 2Q          .  D      F       .      M            .            A      . FE,2R
         P    B 2Q          .  D      F       .     M             .            A      . FE,2R
         P    B 2Q          .  D      F       .     M             .            A      . FE,2R
         P   B  R2          .  D      F       .      M            .            A      . FE,2Q
         P    B R2          .  D      F       .       M           .            A      . FE,2Q
         P    B R2          .  D      F       .        M          .            A      . FE,2Q
  170.0P - B R2- - - - -.- D - - F - - - . - - -M- - - - -.- - - - - A - - - . FE,2Q
         P    B R2         . D        F       .      M            .            A      . FE,2Q
         P    B R2         . D        F       .    M              .            A      . FE,2Q
         P   B  R2         . D        F       .M                  .            A      . FE,2Q
         P   B  R2         . D        F     M.                    .            A      . FE,2Q
         P   B  R2         . D        F    M .                    .            A      . FE,2QR
         P   B   2         . D        F  M   .                    .            A      . FE,2QR
         P   B   2         . D        F  M   .                    .            A      . FE,2QR
         P   B   2         . D        F M    .                    .            A      . FE,2R
         P   B    Q2       . D        F M    .                    .            A      . FE,2R
  180.0P -B-  -Q2 - - - -.-D- - - F M - . - - - - - - - - -.- - - - - A - - - . FE,2R
         P   B    Q2       . D        F    M .                    .            A      . FE,2R
         P   B    Q2       .  D       F    M .                    .            A      . FE,2R
         P   B    Q2       .  D       F     M.                    .            A      . FE,2R
         P   B    Q2       .  D       F      M                    .            A      . FE,QR
         P   B    Q2       .  D       F      .M                   .            A      . FE,QR
         P   B    Q2       .  D       F      . M                  .            A      . FE,QR
         P   B    Q2       .  D       F      .  M                 .            A      . FE,QR
         P   B    Q 2      .  D       F      .  M                 .            A      . FE,QR
         P   B    Q 2      .  D       F      .   M                .            A      . FE
  190.0P -B-  RQ-2- - - -.- D - - F - - - . - M - - - - - - -.- - - - - A - - - . FE
         P   B    RQ 2     .  D       F      .   M                .            A      . FE
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TIME	DAU	USINVL	DLRURR	RSRUR	DDR	RNRTS	MTL	DBO	ATBA	SINVL	RDEM
	RAUF	RUSUR	TLRURR	USSRUI	PBR	DTDR	PMR	DSIARP		SVCAC	RUSUR
	RAU	URINV1	SRUCRL	RSRUUR	SLQ	DUI	AMR	DRSRFD	PTBA		LRURR
	ROE	LRUDR	LRURR	BUSRUI	BSS	DRD	AMS	RRSFD		FHP	
	MTBO	RNRTS	URINV3	DSRURR	ARQP	DRR	RPSFD	RINTRL	PWDR	RAU	TRTD
	RDEM	URINV2	RURS	BSRURR	ARQ	DCR	PINTRL	RARFD		ROE	RARFD
			SINVL	BSSRUI	IOR	DAPQ	RAPFD		BMXW		RAPFD
	QF1	RRF3		SRUCR	DBO	DAR				USINVL	
	QF2		SRURRF			DSI			TRTD	URINV2	
	RRF1										
	RRF2										
E-00	E-00	E-00	E-00	E-00	E-03	E-03	E-00	E-00	E-00	E-00	E-00
	E-03	E-00	E-00	E-00	E-03	E-03	E-00	E-00		E-00	E-00
	E-00	E-03	E-00	E-00	E-00	E-00	E-00	E-00	E-00		E-00
	E-00	E-00	E-00	E-00	E-00	E-00	E-03	E-00		E-00	
	E-00	E-03	E-00	E-03	E-00	E-00	E-00	E-00	E-00	E-00	E-03
	E-00	E-00	E-00	E-00	E-03	E-06	E-00	E-00		E-00	E-00
			E-00	E-00	E-00	E-03	E-00		E-00		E-00
	E-00	E-00		E-00	E-00	E-06				E-00	
	E-00		E-00			E-00			E-03	E-00	
	E-00										
	E-00										
0.00	4.167	0.000	1.0000	0.0000	200.00	0.00	17.143(2)	0.0000	80.000	80.000	1.2000
	166.67	0.0000	0.0000	0.000	800.00	0.00	0.0000	9.000		72.000	0.0000
	4.167	0.00	300.00	0.0000	2.1494	0.0000	0.0000	0.0000	81.540		0.0000
	300.00	0.0000	0.0000	0.0000	8.000(1)	6.0000	0.00	0.0000		300.00	
	250.00	0.00	0.0000	0.00	0.0000	0.0000	0.0000	0.0000	1.4000	4.167	0.00
	1.2000	0.000	0.0000	0.0000	0.00	0.00	0.0000	0.0000		300.00	0.0000
			80.000	15.000	0.0000	0.000	0.0000		0.000		0.0000
	1.0000	.6250		0.0000	0.0000	0.00				0.000	
	1.0000		.5000			10.000			0.00	0.000	
	.5000										
	.5000										

1.00	4.167	.250	1.2252	1.9804	200.11	199.93	17.143	0.0000	79.870	78.840	1.2000
	166.67	1.0070 (3)	.7887	.099	799.56	0.00	0.0000	9.000		72.000	1.0070
	4.167	378.76	280.09	1.9717	2.1501	.1298	0.0000	0.0000	80.381		.7887
	300.00	.7922	.7887	.9479	6.840	6.0000	0.00	0.0000		300.00	
	250.00	199.93	.3616	.06	0.0000	.0008	0.0000	0.0000	1.4008	4.167	199.87
	1.2000 (3)	.039	.2421	.0678	0.00	193.64	0.0000	0.0000		300.00	0.0000
			78.840	14.005	0.0000	.071	0.0000		1.030		0.0000
	1.0000	.7658 (1)		1.9717	0.0000	.00				.250	
	1.0000		.8715 (2)			10.000			199.87	.039	
	.5035										
	.5000										

2.00	4.167	.352	1.2848	2.2442	199.00	229.15	17.143	0.0000	79.661	78.182	1.2000
	166.67	1.2319	.8881	.111	799.11	0.00	0.0000	9.004		72.000	1.2319
	4.167	440.58	245.15	2.2202	2.1442	.3345	0.0000	0.0000	79.714		.8881
	300.00	.8977	.8881	2.3420	6.182	6.0000	0.00	0.0000		300.00	
	250.00	229.15	.6419	6.18	0.0000	.0099	0.0000	0.0000	1.3930	4.167	226.58
	1.2000	.044	.7527	.6306	0.00	215.22	0.0000	0.0000		300.00	0.0000
			78.182	12.258	0.0000	.273	0.0000		1.479		0.0000
	1.0000	.8030		2.2202	0.0000	.00				.352	
	1.0000		.9340			10.004			226.58	.044	
	.6159										
	.5000										

4.00	4.167	.060	1.3575	2.5098	196.78	242.63	17.143	0.0000	79.124	77.651	1.2000
	166.67	1.2000	1.0190	.127	798.64	0.00	0.0000	9.067		72.000	1.2000
	4.167	464.12	188.66	2.5475	2.1322	.8079	0.0000	0.0000	79.166		1.0190
	300.00	1.0039	1.0190	4.2471	5.651	6.0000	0.00	0.0000		300.00	
	250.00	242.63	.6987	80.64	0.0000	.0605	0.0000	0.0000	1.3774	4.167	244.35
	1.2000	.051	1.1204	1.7376	0.00	273.71	0.0000	0.0000		300.00	0.0000
			77.651	9.433	0.0000	.797	0.0000		1.474		0.0000
	1.0000	.8484		2.5475	0.0000	.06				.060	
	1.0000		.9749			10.067			244.35	.051	
	.7902										
	.5000										

9.00	4.167	.061	1.3420	2.4700	191.72	247.05	17.143	0.0000	77.907	76.539	1.2286
	166.67	1.2299 (1)	.9880	.123	798.54	0.00	0.0000	9.755		72.000	1.2299
	4.167	468.97	164.52	2.4699	2.1047	1.3360	0.0000	0.0000	78.016		.9880
	300.00	.9880	.9880	4.1721	4.539 (3)	6.0000	0.00	0.0000		300.00	
	244.17	247.05	.7883	372.85	0.0000	.1974	0.0000	0.0000	1.3421	4.167	247.09
	1.2286	.049	.9839	1.9570	0.00	246.83	0.0000	0.0000		300.00	0.0000
			76.539	8.226 (4)	0.0000	2.017	0.0000		1.368		0.0000
	1.0000	.8387		2.4699	0.0000	.93				.061	
	1.0000		.9723			10.755 (2)			247.09	.049	
	.8309										
	.5000										
10.00	12.500	.060	1.3349	2.4323	190.73	242.80	51.429 (4)	0.0000	77.662	76.307	3.7532
	500.00	1.2079 (3)	.9738	.122	798.48	0.00	0.0000	9.959		72.000	1.2079
	12.500	460.98	162.39	2.4344	2.0992	1.3767	0.0000	0.0000	77.776		.9738
	900.00	.9729	.9738	4.1746	4.307	6.0000	0.00	0.0000		900.00	
	239.79	242.80	.7853	405.31	0.0000	.2110	0.0000	0.0000	1.3351	12.500	243.01
	3.7532 (1)	.049	.9846	1.9646	0.00	244.10	0.0000	0.0000		900.00	0.0000
			76.307	8.119	0.0000	2.262	0.0000		1.355		0.0000
	.9647 (2)	.8343		2.4344	0.0000	1.28				.060	
	1.0000		.9711			10.959			243.01	.049	
	.8324										
	.8800										
11.00	12.500	2.009	1.5808	3.6164	201.58	368.65	51.429	.0022	77.347	73.581	3.6998
	500.00	1.9492	1.4320	.369	798.06	0.00	0.0000	10.175		72.000	1.9492
	12.500	708.83	150.50	3.0000 (1)	2.1582	1.4755	0.0000	.0056	75.580		1.4320
	900.00	1.4466	1.4320	4.4878	1.581 (2)	6.0000	0.00	.0056 (3)		900.00	
	243.26	368.65	.9767	429.86	.4466	.2214	0.0000	0.0000 (4)	1.4110	12.500	364.42
	3.6998	.072	1.1052	1.9907	130.88	349.83	0.0000	0.0000		900.00	0.0000
			73.581	7.525	2.6175	2.542	0.0000		3.766		0.0000
	.9647	.9880		3.5800	.0022	1.71				2.009	
	1.0000		1.0000			11.175			364.42	.072	
	.9746										
	.8800										

12.00	12.638	3.700	1.5998	3.9961	214.28	399.97	51.429	.8050	78.067	71.213	3.6672
	505.52	2.0000	1.5978	1.238	797.42	0.00	0.0000	9.291		71.213	2.0000
	12.638	759.74	123.60	3.0000	2.2252	1.6394	0.0000	2.0124	75.871		1.5978
	900.00	1.5984	1.5978	4.8295	0.000(4)	6.0000	0.00	2.0124		900.00	
	245.42	399.97	1.2219	450.00	2.2206	.2339	0.0000	1.0919	1.4999	12.638	399.95
	3.6672	.080	1.4703	2.1565	4.55	398.65	0.0000	.1110		900.00	.1110
			71.213	6.180	.0910	2.918	0.0000		5.761		0.0000
	.9621	.9999		3.9944	.8050	2.20				3.700(3)	
	.9999 (2)		1.0000			10.291			399.95	.080	
	1.0000 (1)										
	.8961										
13.00	12.951	5.366	1.6000	4.0000	226.86	400.00	51.429	.2128	78.777	69.494	3.6745
	518.03	2.0000	1.6000	2.238	797.15	0.00	0.0000	8.429		69.494	2.0000
	12.951	760.00	97.40	3.0000(3)	12.2896	1.7904	0.0000	.5320	76.002		1.6000
	900.00	1.6000	1.6000	5.0001	0.000	5.7073 (1)	0.00	.5320		900.00	
	244.93	400.00	1.2763	470.82	2.2545	.2656	0.0000	1.8008	1.5880	12.951	400.00
	3.6745	.080	1.5893	2.2962	35.15	400.00	0.0000	.7270		900.00	.7270
			69.494	4.870	.7030	3.315	0.0000		7.482		0.0000
	.9562	1.0000		4.0000 (2)	.2128	2.78				5.366	
	.9989		1.0000			9.429			400.00	.080	
	1.0000										
	.8998										
18.00	14.329	13.977	1.6000	4.0000	293.62	400.00	51.429	.3734	80.766	62.809	3.8874
	573.17	2.0000	1.6000	7.238	794.21	400.00	0.0000	6.000		62.809	2.0000
	14.329	760.00	2.96	3.0000	2.6053	2.2280	0.0000	.9335	76.823		1.1845
	900.00	1.6000	1.1845 (2)	5.0998	0.000	4.4618	0.00	.9335		900.00	
	231.52	400.00	1.0245	562.15	2.5609	.4537	0.0000	1.8060	2.0553	14.329	800.00 (1)
	3.8874	.390	1.3720	2.3997	44.39	792.69	0.0000	.8888		900.00	.8888
			62.809	.148	.8878	5.415	0.0000		16.151		0.0000
	.9303	1.0000		2.9613	.3734	7.20				13.977 (1)	
	.9686		1.0000			7.000			800.00	.390	
	1.0000										
	.9605										

AD-A105 134 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 5/1
A SYSTEM DYNAMICS POLICY ANALYSIS MODEL OF THE AIR FORCE REPARA--ETC(U)
JUN 81 H E TRICHLIN, R E TREMPE
UNCLASSIFIED AFIT-LSSR-19-81 NL

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AD A
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23.00	16.865	22.163	1.6000	4.0000	366.69	400.00	51.429	.4172	81.699	53.365	4.2266
	674.59	2.0000	1.6000	12.238	756.58	400.00	0.0000	4.296		53.365	2.0000
	16.865	760.00	2.99	3.0000	2.9186	2.9953	0.0000	1.0429	77.708		1.1972
	900.00	1.6000	1.1972	5.1000	0.000	3.5877	0.00	1.0429		900.00	
	212.94	400.00	.9573	593.19	2.8688	.8294	0.0000	2.0257	2.5668	16.865	800.00
	4.2266	2.428	1.1962	2.4000	49.85	800.00	0.0000	.9981		900.00	.9981
			53.365	.150	.9970	9.361	0.0000		26.308		0.0000
	.8825	1.0000		2.9931	.4172	14.95				22.163	
	.9325		1.0000			5.296			800.00	2.428	
	1.0000										
	.9975										
24.00	17.543	24.032	1.6000	4.0000	382.58	400.00	51.429	.4264	81.953	51.302	4.3139
	701.38	2.0000	1.6000	13.238	744.63	400.00	.1266(2)	4.087		51.302	2.0000
	17.535	760.00	3.00	3.0000	2.9835	2.9494	0.0000(3)	1.0660	77.900		1.1981
	899.56	1.6000	1.1981	5.1000	0.000	3.4806	0.00	1.0660		900.00	
	208.52	400.00	.9581	595.32	2.9325	.8592(1)	0.0000	2.0709	2.6780	17.535	800.00(1)
	4.3139	2.830	1.1974	2.4000	50.97	800.00	0.0000	1.0204		899.56(4)	1.0204
			51.302	.150	1.0193	10.145	0.0000		28.580		0.0000
	.8699	1.0000		2.9952	.4264	17.06				24.032	
	.9272		1.0000			5.087			800.00	2.830	
	1.0000										
	1.0000(5)										
25.00	18.228	25.967	1.6000	4.0000	398.86	400.00	51.429	.4357	83.249	49.375	4.3577
	723.30	2.0000	1.6000	14.238	730.12	400.00	1.2146	2.786		49.375	2.0000
	18.082	760.00	3.00	3.0000	3.0491	2.8491	.1052	1.0893	78.935		1.1987
	892.81	1.6000	1.1987	5.1000	0.000	2.8674	105.21	1.0893		900.00	
	204.88	400.00	.9587	596.81	2.9970	1.0292	2.1041	2.1169	2.7920	18.082	800.00
	4.3577	3.232	1.1982	2.4000	52.10	800.00	.8393	1.0431		892.81	1.0431
			49.375	.150	1.0420	10.926	1.2446		30.918		1.2446
	.8596	1.0000		2.9967	.4357	19.38				25.967	
	.9227		1.0000			3.891			800.00	3.232	
	1.0000										
	1.0000										

27.00	18.307	29.867	1.6000	4.0000	431.75	400.00	51.429	1.0720	87.412	49.162	4.3397
	725.81	2.0000	1.6000	16.238	709.06	400.00	1.2302	0.000(1)		49.162	2.0000
	18.145	760.00	3.00	3.0000	3.1767	1.9600	.1061	2.6801	79.524		1.1994
	892.07	1.6000	1.1994	5.1000	0.000	2.0000(2)	106.08	0.0000		900.00	
	205.56	400.00	.9594	598.55	3.1242	1.1275	2.1216	1.5937	3.0223	18.145	800.00
	4.3397	4.034	1.1992	2.4000	52.49	800.00	1.0360	1.0395		892.07	1.0395
			49.162	.150	1.0498	12.483	2.0626		35.620		2.0626
	.8584	1.0000		2.9985	1.0720	24.69				29.867	
	.9154		1.0000			.616			800.00	4.034	
	1.0000										
	1.0000										
28.00	18.398	31.804	1.6000	4.0000	449.18	400.00	51.429	2.1406	88.208	48.919	4.3353
	728.72	2.0000	1.6000	17.238	703.56	400.00	1.9022	0.000		48.919	2.0000
	18.218	760.00	3.00	3.0000	3.2413	1.7313	.8717	5.3516	79.317		1.1996
	891.22	1.6000	1.1996	5.1000	0.000	2.0000	47.22	0.0000		900.00	
	205.57	400.00	.9596	599.03	3.2081	.9375	.9443	.7245	3.1443	18.218	800.00
	4.3353	4.434	1.1994	2.4000	33.26	800.00	.6069	.6426		891.22	.6426
			48.919	.150	.6651	13.257	1.4659		37.957		1.4659
	.8571	1.0000		2.9990	2.1406	27.68				31.804	
	.9126		1.0000			.047			800.00	4.434	
	1.0000										
	1.0000										
29.00	19.030	33.745	1.6000	4.0000	466.63	400.00	51.429	2.8406	88.301	47.294	4.3504
	748.96	2.0000	1.6000	18.238	697.43	400.00	3.6967	0.000		47.294	2.0000
	18.724	760.00	3.00	3.0000	3.3049	1.6421	2.8109	7.1016	79.369		1.1997
	885.53	1.6000	1.1997	5.1000	0.000	2.0000	42.55	0.0000		900.00	
	203.55	400.00	.9597	599.35	3.2903	.8482	.8510	.2706	3.2664	18.724	800.00
	4.3504	4.834	1.1996	2.4000	14.62	800.00	.4383	.2789		885.53	.2789
			47.294	.150	.2923	14.027	.8924		40.299		.8924
	.8475	1.0000		2.9993	2.8406	30.91				33.745	
	.9102		1.0000			.043			800.00	4.834	
	1.0000										
	1.0000										

30.00	0.000	35.774	1.6000	4.0000	484.48	400.00	0.000	3.1879	88.333	45.102	0.0000
	100.00	2.0000(3)	1.6000	19.238	690.44	400.00	0.0000	0.000		45.102	2.0000
	2.500	760.00	3.00	3.0000	3.3691	1.6118	0.0000	7.9697	79.560		1.1998
	0.00	1.6000	1.1998	5.1000	0.000	2.0000	0.00	0.0000		0.00(1)	
	233.14	400.00	.9598	599.57	3.3638	.8148	0.0000(2)	.0894	3.3914	2.500	800.00
	0.0000	5.235	1.1998	2.4000	5.30	800.00	.4123	.1004		0.00	.1004
			45.102	.150	.1059	14.795	.8300		42.729		.8300
	1.0000	1.0000		2.9996	3.1879	34.37				35.774	
	.9083		1.0000			.041			800.00	5.235	
	1.0000										
	.5000										
31.00	0.000	33.374	1.6000	4.0000	480.31	400.00	0.000	3.3174	87.533	46.770	0.0000
	100.00	2.0000	1.6000	20.238	683.09	400.00	0.0000	0.000(3)		46.770	2.0000
	2.500	760.00	3.00	3.0000	3.3561	1.6024	0.0000	8.2936	79.116		1.1999
	0.00	1.6000	1.1999	5.1000	0.000	2.0000	0.00	0.0000(1)		0.00	
	227.40	400.00	.9599	599.72	3.3559	.8038	0.0000	.0273	3.3621	2.500	800.00
	0.0000	5.635	1.1998	2.4000	.24	800.00	.0060	.0323		0.00	.0323
			46.770	.150	.0047	15.559	.0291		40.729		.0291
	1.0000	1.0000		2.9997	3.3174	38.06				33.374	
	.9067		1.0000			.849(2)			800.00	5.635	
	1.0000										
	.5000										
32.00	0.000	30.976	1.6000	4.0000	473.57	400.00	0.000	2.7199	87.344	48.011	0.0000
	100.00	1.9648	1.6000	21.238	676.59	400.00	0.0000	.040		48.011	1.9648
	2.500	758.80	3.00	3.0000	3.3339	1.5997	0.0000	6.7998	79.035		1.1999
	0.00	1.6000	1.1999	5.1000	0.000	2.0000	0.00	.8006(2)		0.00	
	222.73	400.00	.9599	599.81	3.3299	.8005	0.0000	.6041	3.3150	2.500	800.00
	0.0000	6.035	1.1999	2.4000	3.97	800.00	.0000	.0910		0.00	.0910
			48.011	.150	.0794	16.319	.0001		38.729		.0001
	1.0000	1.0000		2.9998	2.7199	41.99				30.976	
	.9054		1.0000			1.040(1)			800.00	6.035	
	.9824										
	.5000										

33.00	0.000	28.906	1.5031	3.0550	466.78	288.36	0.000	2.0118	87.349	49.445	0.0000
	100.00	1.2423	1.5031	21.978	670.43	503.60	0.0000	.040		49.445	1.2423
	2.500	537.41	3.00	3.0000	3.3112	1.5938	0.0000	5.0295	78.947		1.2000
	0.00	1.2220	1.2000	5.1000	0.000	2.0000	0.00	.7992		0.00	
	218.99	288.36	.9599	599.88	3.2919	.7991	0.0000	1.1696	3.2675	2.500	791.52
	0.0000	6.331	1.1999	2.4000	19.35	791.23	.0000	.4023		0.00	.4023
			49.445	.150	.3869	17.072	.0000		36.734		.0000
	1.0000	.9394		2.9999	2.0118	46.14				28.906	
	.9046 (1)		1.0000			1.040			791.52	6.331 (2)	
	.6211										
	.5000										
36.00	0.000	24.055	1.2320	2.0000	444.23	200.00	0.000	1.3264	87.344	55.026	0.0000
	100.00	1.0000	1.2320	19.512	652.80	600.00	0.0000	.040		55.026	1.0000
	2.500	380.00 (1)	3.00 (2)	3.0000 (3)	3.2339	1.5967	0.0000	3.3161	78.681		1.2000
	0.00	.8000	1.2000	5.1000	0.000	2.0000	0.00	.7974		0.00	
	220.15	200.00	.9600	599.97	3.1950	.7974	0.0000	1.5783	3.1096	2.500	800.00
	0.0000	5.345	1.2000	2.4000	38.89	800.00	-.0000	.7789		0.00	.7789
			55.026	.150	.7778	19.307	.0000		30.739		.0000
	1.0000	.7700		3.0000	1.3264	59.93				24.055	
	.9141 (4)		1.0000			1.040			800.00	5.345	
	.5000										
	.5000										
37.00	0.000	22.455	1.2320	2.0000	423.57	200.00	0.000	1.2454	87.342	57.012	0.0000
	100.00	1.0000	1.2320	18.512	648.10	600.00	0.0000	.040		57.012	1.0000
	2.500	380.00	3.00	3.0000	3.1587	1.5979	0.0000	3.1135	78.445		1.2000
	0.00	.8000	1.2000	5.1000	0.000	2.0000	0.00	.7985		0.00	
	222.42	200.00	.9600	599.98	3.1192	.7985	0.0000	1.5902	2.9650	2.500	800.00
	0.0000	4.945	1.2000	2.4000	39.56	800.00	-.0000	.7915		0.00	.7915
			57.012	.150	.7912	20.044	.0000		28.739		.0000
	1.0000	.7700		3.0000	1.2454	64.95				22.455	
	.9207		1.0000			1.040			800.00	4.945	
	.5000										
	.5000										

43.00	0.000	12.900	1.2320	2.0000	299.36	200.00	0.000	.7447	87.383	68.999	0.0000
	100.00	1.0000	1.2320	12.512	603.61	0.00 (2)	0.0000	.040		68.999	1.0000
	2.500	380.00	3.00	3.0000	2.6630	1.5532	0.0000	1.8617 (3)	76.987		1.2000
	0.00	.8000	1.2000	5.1000	0.000	2.0000	0.00	.7993		0.00	
	225.12	200.00	.9600	600.00	2.6231	.7992	0.0000	1.5986	2.0955	2.500	200.00
	0.0000	2.545	1.2000	2.4000	39.96	800.00	-.0000	.7993		0.00	.7993
			68.999	.150	.7993	24.356	.0000		16.785		.0000
	1.0000	.7700		3.0000	.7447	99.20				12.900 (1)	
	.9647		1.0000			1.040			200.00	2.545	
	.5000										
	.5000										
44.00	0.000	11.900	1.2320	2.0000	277.86	200.00	0.000	.6810	87.949	70.998	0.0000
	100.00	1.0000	1.2320	11.512	606.99	0.00	0.0000	.034		70.998	1.0000
	2.500	380.00	3.00	3.0000	2.5650	.9926	0.0000	1.7024	76.718		1.2000
	0.00	.8000	1.2000	5.1000	0.000	2.0000	0.00	.6817		0.00	
	226.86	200.00	.9600	600.00	2.5251	.6697	0.0000	1.5657	1.9450	2.500	200.00
	0.0000	2.145	1.2000	2.4000	39.89	200.05	-.0000	.7974		0.00	.7974
			70.998	.150	.7978	24.588	.0000		15.385		.0000
	1.0000	.7700		3.0000	.6810	105.52				11.900	
	.9703		1.0000			1.034			200.00	2.145	
	.5000										
	.5000										
45.00	0.000	10.900	1.2320	2.0000	256.08	200.00	0.000	.7364	88.314	72.981	0.0000
	100.00	1.0000	1.2320	10.512	613.97	0.00	0.0000	.022		72.000	1.0000
	2.500	380.00	3.00	3.0000	2.4614	.6394	0.0000	1.8410	77.118		1.2000
	0.00	.8000	1.2000	5.1000	.981	2.0000	0.00	.4431		0.00	
	231.04	200.00	.9600	600.00	2.1177	.4329	0.0000	1.3483	1.7926	2.500	200.00
	0.0000	1.745	1.2000	2.4000	0.00	200.00	-.0000	.7514		0.00	.7514
			72.981	.150	0.0000	24.680	.0000		13.985		.0000
	1.0000	.7700		3.0000	.7364	111.97				10.900	
	.9752		1.0000			1.022			200.00	1.745	
	.5000										
	.5000										

46.00	0.000	9.900	1.2320	2.0000	233.99	200.00(2)	0.000	.4056	88.478	74.875	0.0000
	100.00	1.0000	1.2320	9.512	621.46	0.00	0.0000	.015		72.000	1.0000
	2.500	380.00	3.00	3.0000	2.3517	.4829	0.0000	1.0139	78.142		1.2000
	0.00	.8000	1.2000(3)	5.1000	2.875(1)	2.0000	0.00	.2950		0.00	
	234.53	200.00	.9600	600.00	1.4233	.2901	0.0000	1.0177	1.6380	2.500	200.00
	0.0000	1.345	1.2000	2.4000	0.00	200.00	-.0000	.6192		0.00	.6192
			74.875	.150	0.0000	24.765	.0000		12.585(2)		.0000
	1.0000	.7700		3.0000	.4056	118.53				9.900	
	.9794		1.0000			1.015			200.00	1.345	
	.5000										
	.5000										
6C.00	5.556	0.000	1.0000	.0000	0.00	.00	22.857	.0000	86.843	86.843	1.7603
	222.22	0.0000	.0000	.000	719.44	0.00	0.0000	2.105		72.000	0.0000
	5.556	.00	254.29	.0000	0.0000	.0274	0.0000	.0000	86.843		.0000
	400.00	.0000	.0000	.3704	14.843	2.4640	0.00	.0000		400.00	
	227.23	.00	.0000	461.70	.0000	.0242	0.0000	.0000	0.0000	5.556	.00
	1.7603	.000	.0000	.3866	0.00	.00	-.0000	.0000		400.00	.0000
			86.843	12.715	0.0000	24.570	.0000		.000		.0000
	1.0000	.6250		.0000	.0000	206.84				0.000	
	.9990		.5000			3.105			.00	.000	
	.5000										
	.5044										
76.00	5.556	.081	1.5263	3.2390	146.57	323.87	22.857	.0000	81.664	79.664	1.6188
	222.22	1.6189(2)	1.5263	6.436	797.28	0.00	0.0000	6.001		72.000	1.6189
	5.556	615.32	2.99	3.0000	1.8404	1.3101	0.0000	.0000	80.993		1.1951
	400.00	1.2956	1.1951(1)	5.1000	7.864	4.4618	0.00	.0000		400.00	
	247.10	323.87	1.0012	588.00	-.0000	.2794	0.0000	.0000	1.0260	5.556	323.88
	1.6188	.102	1.2823	2.4000	.00	323.97	-.0000	.0000		400.00	.0000
			79.864	.149	.0000	25.769	.0000		1.799		.0000
	1.0000	.9539		2.9878	.0000	272.09				.081	
	1.0000		1.0000			7.001			323.88	.102	
	.9709										
	.5044										

87.00	5.556	.079	1.5069	3.1543	230.67	315.66	22.857	.0000	78.211	75.847	1.5737
	222.22	1.5753	1.5069	7.966	794.03	0.00	0.0000	9.054		72.000	1.5753
	5.556	599.61	3.00	3.0000	2.3093	1.7085	0.0000	.0000	77.625		1.1999
	400.00	1.2617	1.1999	5.1000	3.847 (2)	6.0000	0.00	.0000		400.00	
	254.17	315.66	.9599	599.87	-.0000	.2718	0.0000	.0000	1.6147	5.556	315.54
	1.5737	.726	1.1999	2.4000	.00	314.97	-.0000	.0000		400.00	.0000
			75.847	.150	.0000	26.078	.0000		2.365		.0000
	1.0000	.9418		2.9999	.0000	297.92				.079	
	1.0000		1.0000			10.054 (1)			315.54	.726	
	.9569										
	.5044										
92.00	5.556	.074	1.4568	2.9718	225.01	296.72	22.857	.0000	76.684	74.245	1.4741
	222.22	1.4755	1.4568	8.256	797.84	0.00	0.0000	10.487		72.000	1.4755
	5.556	563.26	3.00 (2)	3.0000	2.2802	1.8025	0.0000	.0000	76.000		1.2000
	400.00	1.1887	1.2000	5.1000	2.245 (1)	6.0000	0.00	.0000		400.00	
	271.34	296.72	.9600	599.99	.0226	.2976	0.0000	.0000	1.5751	5.556	296.99
	1.4741	.843	1.2000	2.4000	12.93	298.04	-.0000	.0000		400.00	.0000
			74.245	.150	.2587	26.101	.0000		2.440		.0000
	1.0000	.9105		3.0000	.0000	306.00				.074	
	1.0000		1.0000			11.487			296.99	.843 (2)	
	.9430										
	.5044										
200.00	5.556	.076	1.4764	3.0427	234.56	303.98	22.857	.1296	87.907	73.361	1.5151
	222.22	1.5158	1.4764	36.738	785.16	0.00	0.0000	.451		72.000	1.5158
	5.556	577.33	3.00	3.0000	2.3300	.6163	0.0000	.3241	76.124		1.2000
	400.00	1.2171	1.2000	5.1000	1.361	2.0000	0.00	.3241		400.00	
	264.01	303.98	.9600	600.00	.9530	.3104	0.0000	.6974	1.6419	5.556	304.12
	1.5151	12.235	1.2000	2.4000	15.79	304.86	-.0000	.3604		400.00	.3604
			73.361	.150	.3158	26.246	.0000		13.848		.0000
	1.0000	.9227		3.0000	.1296	329.12				.076	
	1.0000		1.0000			1.451			304.12	12.235	
	.9543										
	.5044										

APPENDIX F

RESULTS FOR EXPERIMENTAL RUN 2

(HYPOTHETICAL SCENARIO FLYING HOUR PROGRAM
INPUT FUNCTION)

Format Conventions

The output of this appendix has been prepared using the following format conventions.

Graphical Output

1. Each variable is represented by an identifying character. A legend relating variable names with their plotting character appears at the head of the output.

2. Multiple scales are used. The scale for a particular variable (or variables) being designated with the plotting character for the variable.

3. The vertical scale is TIME (in weeks).

4. Variables with coincident plot positions are represented by the character for the variable which appears first in the legend for plotting characters. The groups of coincident variables are listed down the right side of the output in line with their coincident plot position.

Tabular Output

1. The names of the tabulated quantities are printed at the beginning of the output.

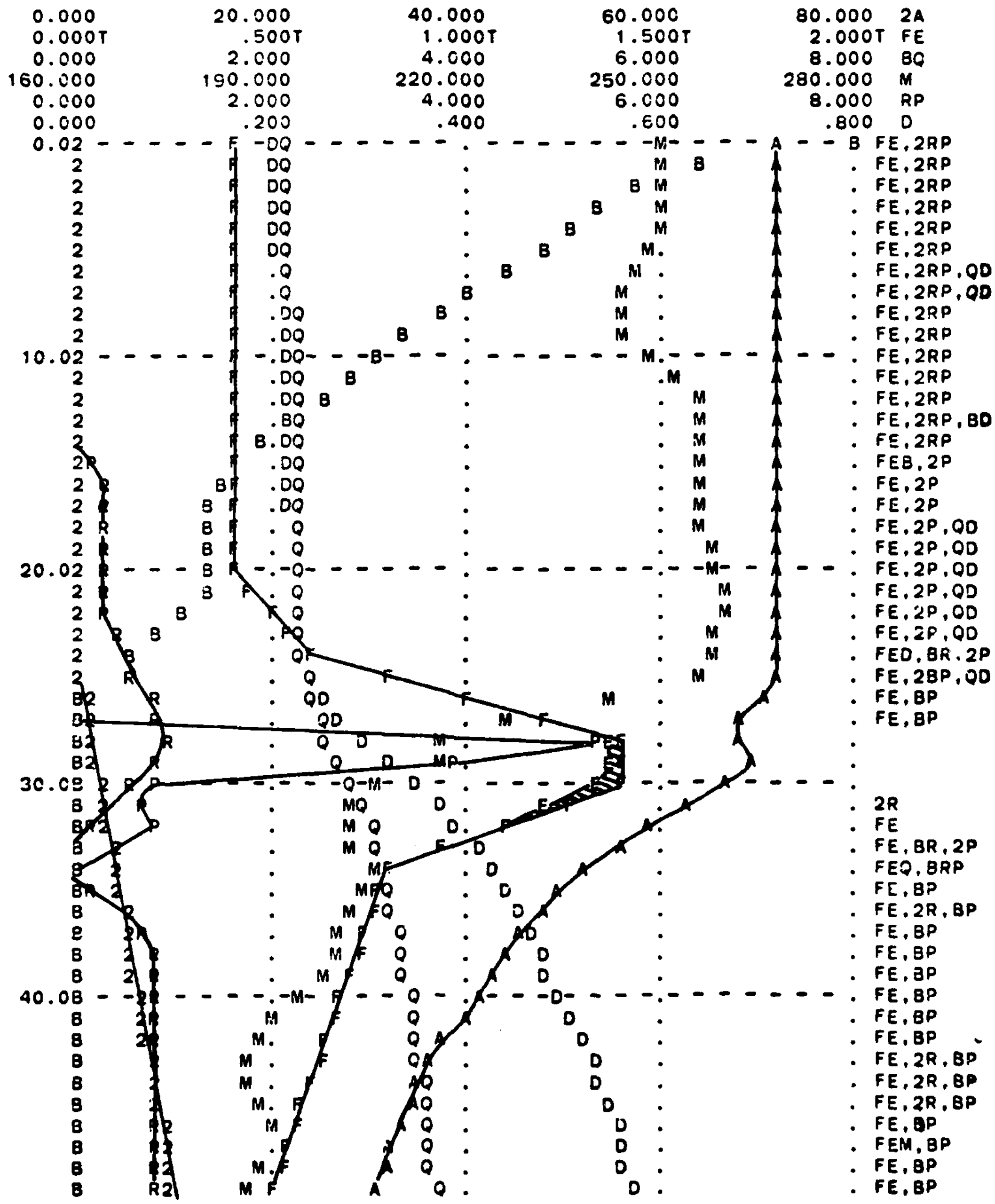
2. Scale factors for the printed quantities are given under the names for the tabulated quantities. The scale factors follow the normal scientific notation convention, e.g., E - 03 = $*10^3$ (or move the decimal point three places to the left of

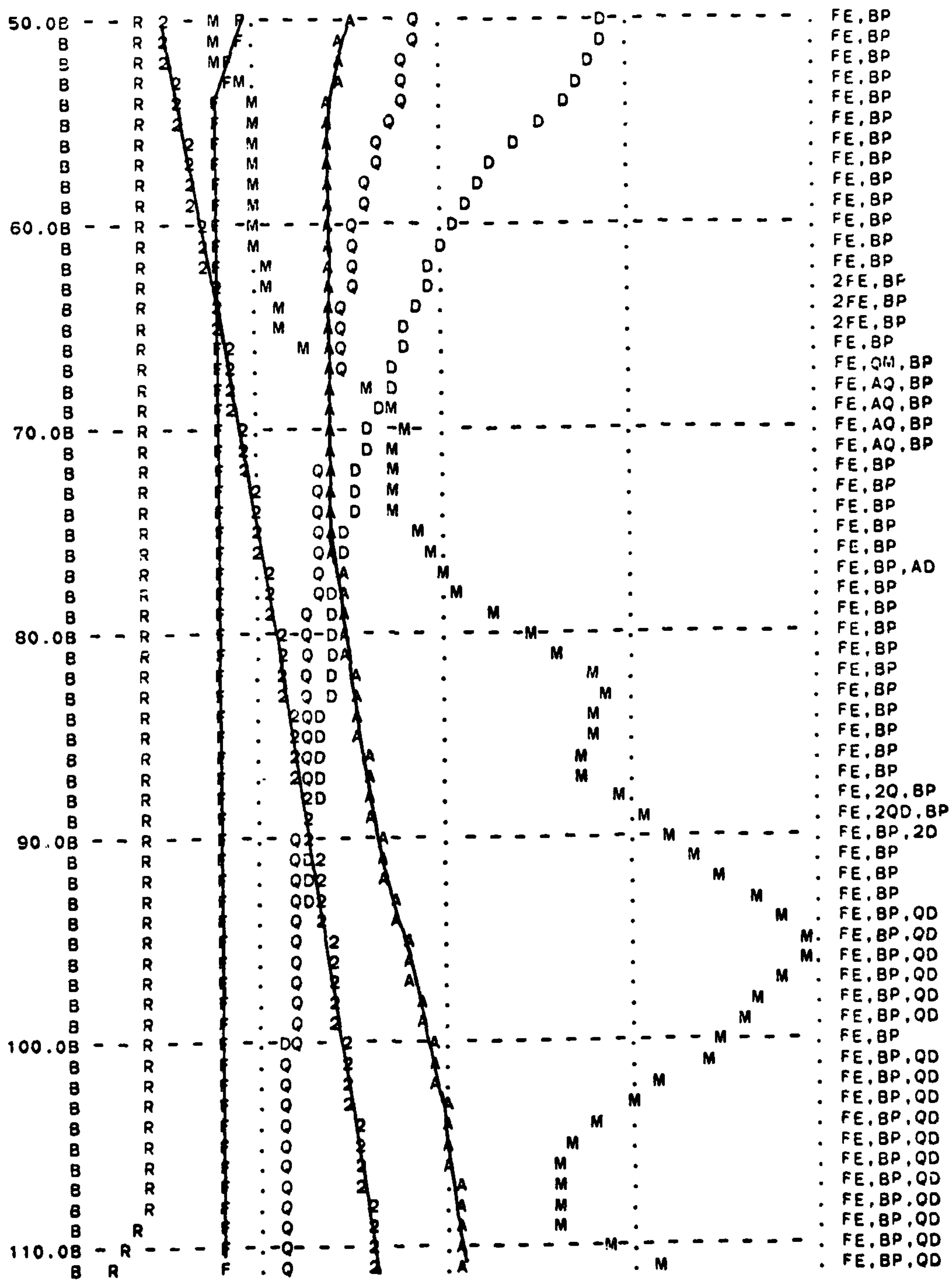
the printed position).

3. The two columns on the right contain a summary of the more significant quantities.

REPARABLE ASSETS SYSTEM POLICY ANALYSIS MODEL

URINV2=2 SVCAC=A FHP=F ROE=E BSS=B SLQ=Q MTBD=M RARFD=R
RAPFD=P DDR=D





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60.0B
70.0B
80.0B
90.0B
100.0B
110.0B
FE,BP
FE,BP
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FE,BP
FE,BP
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FE,AQ,BP
FE,AQ,BP
FE,AQ,BP
FE,BP
FE,BP
FE,BP
FE,BP
FE,BP
FE,BP,AD
FE,BP
FE,BP
FE,BP
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FE,BP
FE,BP
FE,BP
FE,BP
FE,BP
FE,BP
FE,2Q,BP
FE,2QD,BP
FE,BP,2D
FE,BP
FE,BP
FE,BP
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD
FE,BP,QD

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     B  R        F  . Q       2    .A              .   M          . FE,BP,QD
     B  R        F  . Q       2    .A              .     M        . FE,BP,QD
     B  R        F  . Q       2    .A              .     M        . FE,BP,QD
     B  R        F  . Q       2    .A              .  M           . FE,BP,QD
     B  R        F  . Q        2   .A              M              . FE,BP,QD
     B  R        F  . Q        2   .A            M .              . FE,BP,QD
     B  R        F  . Q        2   .A          M   .              . FE,BP,QD
     B  R        F  . Q        2   .A       M      .              . FE,BP,QD
120.0B -R- - - - F -.-Q- - - - -2- .A- -M- - - - -.- - - - - - - - . FE,BP,QD
     B  R        F  . Q          2 .AM             .              . FE,BP,QD
     B  R        F  . Q          2 MA              .              . FE,BP,QD
     B  R        F  . Q          2 .A M            .              . FE,BP,QD
     B  R        F  . DQ          2 .A    M        .              . FE,BP
     B  R        F  .  Q          2 .A     M       .              . FE,BP,QD
     B  R        F  .  Q          2 A       M      .              . FE,BP,QD
     B  R        F  .  Q           2A      M       .              . FE,BP,QD
     B  R        F  .  Q           2A     M        .              . FE,BP,QD
     B  R        F  .  Q           2A     M        .              . FE,BP,QD
     B  R        F  .  Q           2A     M        .              . FE,BP,QD
130.0B -R- - - - F -.- Q - - - - -2A - -M- - - - -.- - - - - - - - . FE,BP,QD
     B  R        F  .  Q            2    M         .              . 2A,FE,BP,QD
     B  R        F  .  Q            2     M        .              . 2A,FE,BP,QD
     B  R        F  .  Q            2     M        .              . 2A,FE,BP,QD
     B  R        F  .  Q            2     M        .              . 2A,FE,BP,QD
     B  R        F  .  Q            A2     M       .              . FE,BP,QD
     B  R        F  .  Q            A2       M     .              . FE,BP,QD
     B  R        F  .  Q           A.2         M   .              . FE,BP,QD
     B  R        F  .  Q           A. 2         M  .              . FE,BP,QD
     B  R        F  .  Q           A. 2           M.              . FE,BP,QD
140.0B -R- - - - F -.- Q - - - - -A. 2 - - - - - M.- - - - - - - - . FE,BP,QD
     B  R        F  .  Q           A. 2          M .              . FE,BP,QD
     B  R        F  .  Q           A.  2         M .              . FE,BP,QD
     B  R        F  .  Q           A.  2        M  .              . FE,BP,QD
     B  R        F  .  Q           A.  2        M  .              . FE,BP,QD
     B  R        F  .  Q           A.  2       M   .              . FE,BP,QD
     B  R        F  .  Q           A.   2     M    .              . FE,BP,QD
     B  R        F  .  Q           A.   2    M     .              . FE,BP,QD
     B  R        F  .  Q           A.   2   M      .              . FE,BP,QD
     B  R        F  .  Q           A.   2   M      .              . FE,BP,QD
150.0B -R- - - - F -.- Q - - - - -A. - -2- M - - -.- - - - - - - - . FE,BP,QD
     B  R        F  .  Q           A.    2 M       .              . FE,BP,QD
     B  R        F  .  Q           A.    2 M       .              . FE,BP,QD
     B  R        F  .  Q           A.     2 M      .              . FE,BP,QD
     B  R        F  .  Q           A.     2    M   .              . FE,BP,QD
     B  R        F  .  Q          A .     2     M  .              . FE,BP,QD
     B  R        F  .  Q          A .     2       M.              . FE,BP,QD
     B  R        F  .  Q          A .     2        M              . FE,BP,QD
     B  R        F  .  Q          A .     2        .M             . FE,BP,QD
     B  R        F  .  Q          A .     2        .M             . FE,BP,QD
160.0B R - - - - F -.- Q - - - - A . - - 2 - - - -.M - - - - - - - . FE,BP,QD
      B R        F  .  Q          A .     2        .M             . FE,BP,QD
      B R        F  .  Q          A .     2        .M             . FE,BP,QD
      B R        F  .  Q          A .     2        M              . FE,BP,QD
      B R        F  .  QD         A .     2        M              . FE,BP
      B R        F  .  QD         A .     2       M.              . FE,BP
      B R        F  .  QD         A .      2      M.              . FE,BP
      B R        F  .  QD         A .      2       M              . FE,BP
      B R        F  .  QD         A .      2       M              . FE,BP
      B R        F  .  QD         A .      2       .M             . FE,BP
170.0B R - - - - F -.-QD - - - - A . - - -2- - - - -.-M- - - - - - - . FE,BP
      B R        F  .  QD         A .      2       M              . FE,BP
      B R        F  .  Q          A .      2    M  .              . FE,BP,QD
      B R        F  .  Q          A .      2  M    .              . FE,BP,QD
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      B R            F   . Q          A  .       2 M         .                  . FE,BP,QD
      B R            F   . Q          A  .       2           .                  . FE,2M,BP,QD
      B R            F   . Q          A  .      M2           .                  . FE,BP,QD
      B R            F   . Q          A  .      M2           .                  . FE,BP,QD
      B  R           F   . Q          A  .     M  2          .                  . FE,BP,QD
      B  R           F   . Q          A  .     M  2          .                  . FE,BP,QD
180.0B -R- - - - -   F -.-QD - - - - -A- . - -M- 2 - - - - .- - - - - - - - -  . FE,BP
      B  R           F   . QD        A   .      M 2          .                  . FE,BP
      B  R           F   . QD        A   .       M2          .                  . FE,BP
      B  R           F   .  Q        A   .       M2          .                  . FE,BP,QD
      B  R           F   .  Q        A   .        2          .                  . FE,2M,BP,QD
      B  R           F   .  Q        A   .        2M         .                  . FE,BP,QD
      B  R           F   .  Q        A   .         2M        .                  . FE,BP,QD
      B  R           F   .  Q        A   .         2M        .                  . FE,BP,QD
      B  R           F   .  Q        A   .         2 M       .                  . FE,BP,QD
      B  R           F   .  Q        A   .         2 M       .                  . FE,BP,QD
190.0B -R- - - - -   F -.- Q - - -A- -   . - - - -2-M- - .- - - - - - - - -    . FE,BP,QD
      B  R           F   .  Q       A    .         2 M       .                  . FE,BP,QD
      B R            F   .  Q       A    .         2 M       .                  . FE,BP,QD
      B R            F   .  Q       A    .         2 M       .                  . FE,BP,QD
      B R            F   .  Q       A    .         2   M     .                  . FE,BP,QD
      B R            F   .  Q       A    .         2     M   .                  . FE,BP,QD
      B R            F   .  Q       A    .         2     M   .                  . FE,BP,QD
      B R            F   .  Q       A    .          2      M.                   . FE,BP,QD
      B R            F   .  Q       A    .          2        .M                 . FE,BP,QD
      B R            F   .  Q       A    .          2        . M                . FE,BP,QD
200.0B R - - - - -   F -.- Q - - -A- -   . - - - - 2 - - -.- M - - - - - - -   . FE,BP,QD
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TIME	DAU	USINVL	DLRURR	RSRUR	DDR	RNRTS	MTL	DBO	ATBA	SINVL	RDEM
	RAUF	RUSUR	TLRURR	USSRUI	PBR	DTDR	PMR	DSIARP		SVCAC	RUSUR
	RAU	URINV1	SRUCRL	RSRUUR	SLQ	DUI	AMR	DRSRFD	PTBA		LRURR
	ROE	LRUDR	LRURR	BUSRUI	BSS	DRD	AMS	RRSFD		FHP	
	MTBD	RNRTS	URINV3	DSRURR	ARQP	DRR	RPSFD	RINTRL	PWDR	RAU	TRTD
	RDEM	URINV2	RURS	BSRURR	ARQ	DCR	PINTRL	RARFD		ROE	RARFD
			SINVL	BSSRUI	IOR	DAPQ	RAPFD		BMXW		RAPFD
	QF1	RRF3		SRUCR	DBO	DAR				USINVL	
	QF2		SRURRF			DSI			TRTD	URINV2	
	RRF1										
	RRF2										
E-00	E-00	E-00	E-00	E-00	E-03	E-03	E-00	E-00	E-00	E-00	E-00
	E-03	E-00	E-00	E-00	E-03	E-03	E-00	E-00		E-00	E-00
	E-00	E-03	E-00	E-00	E-00	E-00	E-00	E-00	E-00		E-00
	E-00	E-00	E-00	E-00	E-00	E-00	E-03	E-03		E-00	
	E-00	E-03	E-00	E-03	E-00	E-03	E-00	E-00	E-00	E-00	E-03
	E-00	E-00	E-00	E-00	E-03	E-06	E-00	E-03		E-00	E-03
			E-00	E-00	E-00	E-03	E-00		E-00		E-00
	E-03	E-00		E-00	E-00	E-06				E-00	
	E-00		E-00			E-00			E-03	E-00	
	E-00										
	E-00										
0.00	5.556	0.000	1.0000	0.0000	200.00	0.00	22.857	0.0000	80.000	80.000	1.6000
	222.22	0.0000	0.0000	0.00	800.00	0.00	0.0000	9.000		72.000	0.0000
	5.556	0.00	300.00	0.0000	2.1494	0.0000	0.0000	0.0000	81.540		0.0000
	400.0	0.0000	0.0000	0.0000	8.0000	6.0000	0.00	0.00		400.0	
	250.00	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.0000	1.4000	5.556	0.00
	1.6000	0.000	0.0000	0.0000	0.000	0.00	0.0000	0.00		400.0	0.00
			80.000	15.000	0.0000	0.000	0.0000		0.000		0.0000
	1.0000	.6250		0.0000	0.0000	0.00				0.000	
	1.0000		.5000			10.000			0.00	0.000	
	.9700										
	.5044										

1.00	5.556	.080	1.5073	3.1687	202.00	319.88	22.857	0.0000	79.792	78.464	1.6000
	222.22	1.6000	1.2519	.17 (1)	799.30	0.00	0.0000	9.000		72.000	1.6000
	5.556	606.01	268.15 (2)	3.0000	2.1602	.2077	0.0000	0.0000	80.020		1.2619
	400.0	1.2675	1.2619	1.5005	6.4643	6.0000	0.00	0.00		400.0	
	250.00	319.88	.5786	.09	0.0000	1.29	0.0000	0.0000	1.4140	5.556	319.79
	1.6000	.063	.3874	.1084	0.000	309.83	0.0000	0.00		400.0	0.00
			78.464	13.407 (2)	0.0000	.113	0.0000		1.328		0.0000
	1.0000	.9421		3.1547	0.0000	.00				.080	
	1.0000		1.0000			10.000			319.79	.063	
	.9700										
	.5044										
13.00	5.556	.078	1.4982	3.1214	215.85	311.99	22.857	0.0000 (2)	75.932	74.194	1.5599
	222.22	1.5599	1.2488	2.73	797.83	0.00	0.0000	11.178		72.000	1.5599
	5.556	592.85	75.39	3.0000	2.2333	1.8864	0.0000	0.0000	75.881		1.2488
	400.0	1.2486	1.2488	5.1000	2.1942 (1)	6.0000	0.00	0.00		400.0	
	256.43	311.99	1.0042	564.38	.0241	308.10	0.0000	0.0000	1.5110	5.556	312.02
	1.5599	.062	1.2588	2.4000	15.017	312.53	0.0000	0.00		400.0	0.00
			74.194	3.769	.3003	3.962	0.0000		1.737		0.0000
	1.0000	.9364		3.1221	0.0000	3.74				.078	
	1.0000		1.0000			12.178			312.02	.062	
	.9664										
	.5044										
19.00	5.556	.078	1.4942	3.1074	221.61	310.64	22.857	.1248	75.724	73.370	1.5514
	222.22	1.5516	1.2432	3.50	796.94	0.00	0.0000	11.393		72.000	1.5516
	5.556	590.12	59.23	3.0000	2.2630	1.8768	0.0000	.3120	75.955		1.2432
	400.0	1.2430	1.2432	5.1000	1.3705 (1)	6.0000	0.00	312.00		400.0	
	257.83	310.64	.9965	596.54	.8773	313.74	0.0000	.6277	1.5513	5.556	310.69
	1.5514	.062	1.2467	2.4000	15.234	310.96	0.0000	312.21		400.0	312.21
			73.370	2.962 (2)	.3047	5.794	0.0000		1.726		0.0000
	1.0000	.9339		3.1080	.1248	10.46				.078	
	1.0000		1.0000			12.393			310.69	.062	
	.9579										
	.5044										

21.00	6.250	.086	1.5335	3.3028	223.66	334.01	25.714	.1438	75.726	73.296	1.7363
	250.00	1.7268 (2)	1.3136	3.76	796.40	0.00	0.0000	11.390		72.000	1.7268
	6.250	637.80	54.19	3.0000	2.2736	1.8769	0.0000	.3596	75.972		1.3136
	450.0	1.3211	1.3136 (3)	5.1000	1.2964	6.0000	0.00	359.62		450.0 (1)	
	259.18	334.01	1.0092	598.48	.9530	312.76	0.0000	.6308	1.5656	6.250	332.11
	1.7363	.066	1.2464	2.4000	24.111	322.82	0.0000	312.00		450.0	312.00
			73.296	2.710	.4822	6.393	0.0000		1.799		0.0000
	1.0000	.9584		3.2841	.1438	13.52				.086	
	1.0000		1.0000			12.390			332.11	.066	
	.9584										
	.5100										

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23.00	7.639	.172	1.5959	3.9005	229.29	390.43	31.429	.2410	75.984	72.829	2.1257
	305.56	1.9567	1.5595	5.07	794.83	0.00	0.0000	11.022		72.000	1.9567
	7.639	742.02	28.57	3.0000	2.3022	1.9867	0.0000	.6025	76.037		1.5595
	550.0	1.5602	1.5595	5.1000	.8291	6.0000	0.00	602.48		550.0	
	258.74	390.43	1.2176	599.34	1.4416	315.85	0.0000	.9454	1.6050	7.639	390.28
	2.1257	.078	1.4930	2.4000	31.466	389.29	0.0000	406.80		550.0	406.80
			72.829	1.428	.6293	7.081	0.0000		2.210		0.0000
	1.0000	.9975		3.8986	.2410	16.96				.172	
	1.0000		1.0000			12.022			390.28	.078	
	.9784										
	.5278										

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25.00	11.112	1.114	1.6000	3.9992	240.48	399.99 (7)	45.714	.3886	76.593	71.991	3.1258
	444.50	2.0000 (1)	1.6000	6.97	793.33	0.00	0.0000	10.269		71.991	2.0000
	11.112	759.94	3.00	3.0000	2.3580	2.1309	0.0000	.9716	76.138		1.1999
	800.0	1.5997	1.1999 (4)	5.1000	0.0000 (5)	6.0000	0.00	971.59 (6)		800.0	
	255.94	399.99	1.0553	599.72	2.2848	332.17	0.0000	1.3460	1.6834	11.112	399.99
	3.1258	.326	1.4179	2.4000	73.137	399.71	0.0000	593.65 (7)		800.0	593.65
			71.991	.150	1.4627	7.831	0.0000		3.255		0.0000
	.9908 (3)	1.0000		2.9997	.3886	20.79				1.114	
	.9999 (2)		1.0000			11.269			399.99	.326	
	1.0000 (1)										
	.7579										

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27.00	17.725	5.378	1.6000	4.0000	267.19	400.00	68.571	.3422	77.651	67.702	5.2982
	707.19	2.0000	1.6000	8.97	793.69	0.00	.8690 (2)	9.096		67.702	2.0000
	17.680	760.00	3.00	3.0000	2.4854	2.2443	0.0000	.8555	76.501		1.2000
	1197.0	1.6000	1.2000	5.1000	0.0000	6.0000	0.00	855.55		1200.0	
	225.92	400.00	.9601	599.88	2.4423	354.21	0.0000	1.7244	1.8703	17.680	400.00
	5.2982	1.126	1.2005	2.4000	43.061	400.00	0.0000	862.55		1197.0 (1)	862.55
			67.702	.150	.8612	8.585	0.0000		8.224		0.0000
	.8672	1.0000		2.9999	.3422	25.02				5.378	
	.9959		1.0000			10.096 (4)			400.00	1.126	
	1.0000										
	1.0000 (3)										
28.00	20.440	9.156	1.6000	4.0000	289.85	400.00	72.000	.3810	84.959	68.494	6.2575
	788.80	2.0000	1.6000	9.97	793.28	0.00	1.2123	1.785		68.494 (5)	2.0000
	19.720 (2)	760.00	3.00	3.0000	2.5887	2.0410	.2065	.9525	79.073		1.2000
	1350.7	1.6000	1.2000	5.1000	0.0000	2.4059	206.52	952.46		1400.0	
	215.85	400.00	.9600	599.92	2.5453	910.24 (4)	4.1303	1.7689	2.0290	19.720 (1)	400.00
	6.2575	1.526	1.2000	2.4000	43.393	400.00	2.2942	868.49		1350.7	868.49
			68.494	.150	.8679	8.959	5.2802		12.402		5.2802
	.8288	1.0000		2.9999	.3810	27.28				9.156	
	.9909		1.0000			2.991 (3)			400.00	1.526	
	1.0000										
	1.0000										
29.00	20.387	13.404	1.6000	4.0000	315.75	400.00	72.000	.9311	88.494	68.673	6.2791
	787.73	2.0000	1.6000	10.97	791.47	400.00 (3)	1.8816	0.000		68.673	2.0000
	19.693	760.00	3.00	3.0000	2.7022	1.4499	.8609	2.3278	78.539		1.2000
	1352.4	1.6000	1.2000	5.1000	0.0000	2.0000	46.47 (1)	0.00 (2)		1400.0	
	215.38	400.00	.9600	599.95	2.6590	914.93	.9294	1.3255	2.2102	19.693	800.00
	6.2791	1.926	1.2000	2.4000	43.217	400.00	1.4456	856.53		1352.4	856.53
			68.673	.150	.8643	9.331	3.8978		17.050		3.8978
	.8293	1.0000		2.9999	.9311	29.63				13.404	
	.9843		1.0000			.046 (1)			800.00	1.926	
	1.0000										
	1.0000										

30.00	21.183	17.371	1.6000	4.0000	342.14	400.00	72.000	1.8702	88.509	66.091	6.4451
	803.66	2.0000	1.6000	11.97	782.49	400.00	5.5137	0.000		66.091	2.0000
	20.091	760.00	3.00	3.0000	2.8145	1.4448	4.5624	4.6754	77.822		1.2000
	1327.9	1.6000	1.2000	5.1000	0.0000	2.0000	36.58	0.00		1400.0	
	206.03	400.00	.9600	599.97	2.7868	728.38	.7315	.6054	2.3950	20.091	800.00
	6.4451	2.326	1.2000	2.4000	27.678	799.96	.3952	535.00		1327.9	535.00
			66.091	.150	.5536	10.000	.8419		21.417		.8419
	.8218	1.0000		3.0000	1.8702	32.09				17.371	
	.9767		1.0000			.037			800.00	2.326	
	1.0000										
	1.0000										

33.00	17.133	27.221	1.6000	4.0000	410.86	400.00	54.286(1)	3.0166	88.056	55.448	4.6947
	685.33	2.0000	1.6000	14.97	755.51	400.00	0.0000	0.000		55.448	2.0000
	17.133	760.00	3.00	3.0000	3.0896	1.5884	0.0000	7.5415	78.389		1.2000
	950.0	1.6000	1.2000	5.1000	0.0000	2.0000	0.00	0.00		950.0	
	202.36	400.00	.9600	599.99	3.0882	787.66	0.0000	.0229	2.8760	17.133	800.00
	4.6947	3.526	1.2000	2.4000	1.437	800.00	.1184	27.11		950.0(3)	27.11
			55.448	.150	.0287	12.292	.4473		32.467		.4473
	.8775	1.0000		3.0000	3.0166	40.17				27.221	
	.9526		1.0000			.343(2)			800.00	3.526	
	1.0000										
	.9985(4)										

34.00	15.246	29.130	1.6000	4.0000	426.14	400.00	45.714	3.0165	87.352	52.473	3.8806
	609.83	2.0000	1.6000	15.97	746.82	400.00	0.0000	.040		52.473	2.0000
	15.246	760.00	3.00	3.0000	3.1483	1.5955	0.0000	7.5412	78.452		1.2000
	800.0	1.6000	1.2000	5.1000	0.0000	2.0000	0.00	795.33(1)		800.0	
	206.15	400.00	.9600	599.99	3.1479	795.50	0.0000	.1018	2.9830	15.246	800.00
	3.8806(2)	3.926	1.2000	2.4000	.431	800.00	.0006	8.24		800.0	8.24
			52.473	.150	.0086	13.051	.0032		34.776		.0032
	.9130	1.0000		3.0000	3.0165	43.15				29.130	
	.9453		1.0000			1.040			800.00	3.926	
	1.0000										
	.9910										

54.00	14.005	43.528	1.6000	4.0000	529.12	400.00	22.857	1.6139	87.334	28.561	2.1058
	560.20	2.0000	1.6000	35.97	603.75	400.00	0.0000	.040		28.561	2.0000
	14.005	760.00	3.00	3.0000	3.5404	1.5986	0.0000	4.0347	79.678		1.2000
	400.0	1.6000	1.2000	5.1000	0.0000	2.0000	0.00	799.34		400.0 (1)	
	189.95	400.00	.9600	600.00	3.5004	799.20	0.0000	1.5987	3.7038	14.005	800.00
	2.1058 (2)	11.926	1.2000	2.4000	39.966	800.00	-.0000	799.33		400.0	799.33
			28.561	.150	.7993	27.341	.0000		57.174		.0000
	.9364	1.0000		3.0000	1.6139	139.64				43.528	
	.9007 (3)		1.0000			1.040			800.00	11.926	
	1.0000										
	.9462										

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67.00	14.543	39.376	1.6000	4.0000	349.62	400.00	22.857	.9389	87.326	27.505	1.9645
	581.72	2.0000	1.6000	48.97	600.00	400.00	0.0000	.040		27.505 (2)	2.0000
	14.543	760.00	3.00	3.0000	2.8785	1.5986	0.0000	2.3472	77.601		1.2000
	400.0	1.6000	1.2000	5.1000	0.0000	2.0000	0.00	799.43		400.0	
	203.62	400.00	.9600	600.00	2.8386	799.20	0.0000	1.5988	2.4473	14.543	800.00
	1.9645 (1)	17.126	1.2000	2.4000	39.971	800.00	-.0000	799.42		400.0	799.42
			27.505	.150	.7994	35.345	.0000		58.222		.0000
	.9263	1.0000		3.0000	.9389	231.69				39.376	
	.9000		1.0000			1.040			800.00	17.126	
	1.0000										
	.9699										

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69.00	14.464	38.428	1.5998	3.9931	334.01	399.15	22.857	.8715	87.325	27.654	1.8882
	578.57	1.9932 (1)	1.5998	50.96	600.00	400.77	0.0000	.040		27.654	1.9932
	14.464	756.24	3.00	3.0000	2.8136	1.5986	0.0000	2.1787	77.417		1.2000
	400.0	1.5973	1.2000	5.1000	0.0000	2.0000	0.00	799.44		400.0	
	211.84	399.15	.9600	600.00	2.7786	799.20	0.0000	1.5989	2.3381	14.464	799.92
	1.8882	17.926	1.2000	2.4000	34.990	799.93	-.0000	799.43		400.0	799.43
			27.654	.150	.6998	36.467	.0000		58.072		.0000
	.9277 (3)	.9998		3.0000	.8715	246.82				38.428	
	.9001 (2)		1.0000			1.040			799.92	17.926	
	.9966										
	.9664										

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70.00	14.399	37.911	1.5991	3.9767	326.33	397.51	22.857	.8384	87.324	27.780	1.8628
	575.96	1.9853	1.5991	51.95	600.00	402.41	0.0000	.040		27.780	1.9853
	14.399	755.14	3.00	3.0000	2.7810	1.5985	0.0000	2.0959	77.324		1.2000
	400.0	1.5907	1.2000	5.1000	0.0000	2.0000	0.00	799.42		400.0	
	214.73	397.51	.9600	600.00	2.7458	799.17	0.0000	1.5989	2.2843	14.399	799.92
	1.8628	18.320	1.2000	2.4000	35.218	799.92	-.0000	799.44		400.0	799.44
			27.780	.150	.7044	37.017	.0000		57.946		.0000
	.9290	.9994		3.0000	.8384	254.42				37.911	
	.9013		1.0000			1.040			799.92	18.320	
	.9926										
	.9636										
71.00	14.333	37.397	1.5985	3.9622	319.39	396.10	22.857	.8071	87.324	27.908	1.8786
	573.30	1.9789	1.5985	52.92	600.00	403.84	0.0000	.040		27.908	1.9789
	14.333	752.50	3.00	3.0000	2.7513	1.5985	0.0000	2.0176	77.239		1.2000
	400.0	1.5849	1.2000	5.1000	0.0000	2.0000	0.00	799.40		400.0	
	212.93	396.10	.9600	600.00	2.7156	799.14	0.0000	1.5989	2.2358	14.333	799.94
	1.8786	18.708	1.2000	2.4000	35.734	799.93	-.0000	799.43		400.0	799.43
			27.908	.150	.7147	37.558	.0000		57.817		.0000
	.9302	.9991		3.0000	.8071	262.05				37.397	
	.9045		1.0000			1.040			799.94	18.708	
	.9894										
	.9606										
72.00	14.273	36.898	1.5982	3.9539	313.31	395.35	22.857	.7791	87.323	28.025	1.8864
	570.92	1.9763	1.5982	53.88	600.00	404.64	0.0000	.040		28.025	1.9763
	14.273	751.14	3.00	3.0000	2.7250	1.5985	0.0000	1.9477	77.164		1.2000
	400.0	1.5816	1.2000	5.1000	0.0000	2.0000	0.00	799.41		400.0	
	212.04	395.35	.9600	600.00	2.6887	799.14	0.0000	1.5988	2.1931	14.273	799.98
	1.8864	19.091	1.2000	2.4000	36.228	799.97	-.0000	799.42		400.0	799.42
			28.025	.150	.7246	38.093	.0000		57.700		.0000
	.9313	.9989		3.0000	.7791	269.70				36.898	
	.9097		1.0000			1.040			799.98	19.091	
	.9882										
	.9580										

73.00	14.216	36.404	1.5981	3.9524	307.97	395.24	22.857	.7540	87.323	28.137	1.8877
	568.65	1.9764	1.5981	54.83	600.00	404.76	0.0000	.040		28.137	1.9764
	14.216	750.97	3.00	3.0000	2.7016	1.5986	0.0000	1.8851	77.098		1.2000
	400.0	1.5810	1.2000	5.1000	0.0000	2.0000	0.00	799.43		400.0	
	211.90	395.24	.9600	600.00	2.6650	799.15	0.0000	1.5988	2.1558	14.216	800.00
	1.8877	19.472	1.2000	2.4000	36.587	800.00	-.0000	799.41		400.0	799.41
			28.137	.150	.7317	38.619	.0000		57.587		.0000
	.9324	.9988		3.0000	.7540	277.35				36.404	
	.9164		1.0000			1.040			800.00	19.472	
	.9882										
	.9555										
74.00	14.159	35.909	1.5981	3.9534	302.99	395.36	22.857	.7315	87.322	28.250	1.8809
	566.37	1.9769	1.5981	55.78	600.00	404.65	0.0000	.040		28.250	1.9769
	14.159	751.19	3.00	3.0000	2.6797	1.5986	0.0000	1.8287	77.037		1.2000
	400.0	1.5814	1.2000	5.1000	0.0000	2.0000	0.00	799.46		400.0	
	212.67	395.36	.9600	600.00	2.6430	799.18	0.0000	1.5989	2.1209	14.159	800.01
	1.8809	19.853	1.2000	2.4000	36.762	800.01	-.0000	799.42		400.0	799.42
			28.250	.150	.7352	39.138	.0000		57.473		.0000
	.9335	.9988		3.0000	.7315	285.01				35.909	
	.9241		1.0000			1.040			800.01	19.853	
	.9885										
	.9530										
75.00	14.095	35.398	1.5982	3.9539	298.31	395.39	22.857	.7101	87.322	28.379	1.8598
	563.80	1.9767	1.5982	56.74	600.00	404.61	0.0000	.040		28.379	1.9767
	14.095	751.22	3.00	3.0000	2.6589	1.5986	0.0000	1.7753	76.979		1.2000
	400.0	1.5816	1.2000	5.1000	0.0000	2.0000	0.00	799.49		400.0	
	215.08	395.39	.9600	600.00	2.6220	799.19	0.0000	1.5989	2.0882	14.095	800.00
	1.8598	20.234	1.2000	2.4000	36.932	800.00	-.0000	799.44		400.0	799.44
			28.379	.150	.7386	39.650	.0000		57.344		.0000
	.9347	.9988		3.0000	.7101	292.67				35.398	
	.9322		1.0000			1.040			800.00	20.234	
	.9884										
	.9502										

76.00	14.021	34.868	1.5981	3.9514	293.97	395.10	22.857	.6900	87.321	28.528	1.8390
	560.85	1.9747	1.5981	57.69	600.00	404.88	0.0000	.040		28.528	1.9747
	14.021	750.65	3.00	3.0000	2.6395	1.5986	0.0000	1.7251	76.925		1.2000
	400.0	1.5806	1.2000	5.1000	0.0000	2.0000	0.00	799.50		400.0	
	217.50	395.10	.9600	600.00	2.6024	799.20	0.0000	1.5990	2.0578	14.021	799.98
	1.8390	20.616	1.2000	2.4000	37.157	799.98	-.0000	799.46		400.0	799.46
			28.528	.150	.7431	40.153	.0000		57.194		.0000
	.9361	.9988		3.0000	.6900	300.33				34.868	
	.9403		1.0000			1.040			799.98	20.616	
	.9874										
	.9469										
77.00	13.938	34.319	1.5978	3.9458	290.03	394.51	22.857	.6714	87.321	28.698	1.8193
	557.53	1.9715	1.5978	58.64	600.00	405.45	0.0000	.040		28.698	1.9715
	13.938	749.51	3.00	3.0000	2.6218	1.5986	0.0000	1.6785	76.876		1.2000
	400.0	1.5783	1.2000	5.1000	0.0000	2.0000	0.00	799.50		400.0	
	219.86	394.51	.9600	600.00	2.5843	799.19	0.0000	1.5990	2.0302	13.938	799.97
	1.8193	20.995	1.2000	2.4000	37.432	799.97	-.0000	799.48		400.0	799.48
			28.698	.150	.7486	40.649	.0000		57.024		.0000
	.9376	.9987		3.0000	.6714	307.97				34.319	
	.9481		1.0000			1.040			799.97	20.995	
	.9858										
	.9433										
99.00	10.622	17.891	1.5884	3.7119	233.40	371.36	22.857	.3978	87.312	37.659	1.4966
	424.86	1.8595	1.5884	77.39	600.01	428.73	0.0000	.040		37.659	1.8595
	10.622	705.73	3.00	3.0000	2.3519	1.5987	0.0000	.9945	76.157		1.2000
	400.0	1.4848	1.2000	5.1000	0.0000	2.0000	0.00	799.62		400.0	
	267.27	371.36	.9600	600.00	2.3136	799.16	0.0000	1.5991	1.6338	10.622	800.09
	1.4966	28.496	1.2000	2.4000	38.326	800.08	-.0000	799.52		400.0	799.52
			37.659	.150	.7665	49.692	.0000		48.053		.0000
	1.0000 (1)	.9928		3.0000	.3978	465.96				17.891	
	.9995 (2)		1.0000			1.040			800.09	28.496	
	.9297										
	.7147										

106.00	9.862	12.894	1.5954	3.8843	224.27	388.49	22.857	.3466	87.459	40.558	1.6822
	394.50	1.9433	1.5954	82.92	601.52	0.00(1)	0.0000	.040(2)		40.558	1.9433
	9.862	738.19	3.00	3.0000	2.3053	1.4489	0.0000	.8666	76.034		1.2000
	400.0	1.5537	1.2000	5.1000	0.0000	2.0000	0.00	796.38		400.0	
	237.79	388.49	.9600	600.00	2.2631	793.79	0.0000	1.5995	1.5699	9.862	388.47
	1.6822	30.709	1.2000	2.4000	42.206	471.38	-.0000	799.82		400.0	799.82
			40.558	.150	.8441	51.840	.0000		45.302		.0000
	1.0000	.9971		3.0000	.3466	509.53				12.894	
	.9999		1.0000			1.040			388.47	30.709	
	.9717										
	.6523										
200.00	12.099	.078	1.5006	3.1292	238.96	312.63	22.857	1.5610	88.318	33.060	1.5584
	483.98	1.5590	1.5006	138.60	782.06	0.00	0.0000	.016		33.060(1)	1.5590
	12.099	593.76	3.00	3.0000	2.3522	.6335	0.0000	3.9025	76.180		1.2000
	400.0	1.2517	1.2000	5.1000	0.0000	2.0000	0.00	319.62		400.0	
	256.68	312.63	.9600	600.00	2.3360	318.98	0.0000	.6462	1.6727	12.099	312.77
	1.5584	52.980	1.2000(3)	2.4000	16.232	313.50	-.0000	324.55		400.0	324.55
			33.060	.150	.3246	32.852	.0000		54.612		.0000
	.9722	.9379		3.0000	1.5610	475.08				.078(2)	
	1.0000		1.0000			1.016			312.77	52.980(4)	
	.9672										
	.8447										

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BIOGRAPHICAL SKETCHES OF THE AUTHORS

Squadron Leader Herbert E. Trichlin enlisted in the Royal Australian Air Force in 1964 as an apprentice aircraft electrical fitter. After completing his apprenticeship he served for two and a half years as an electrical fitter in the operational and intermediate maintenance of the Mirage aircraft electrical and missile systems. During this period he obtained his matriculation through part-time studies and was selected for full-time training as an electrical engineer commencing in February 1970. He received his commission in December 1972 and graduated valedictorian of the Darling Downs Institute of Advanced Education in April 1974 with a bachelor's degree in electrical engineering. Since that time he has held appointments as an avionics engineering project officer for F-111C avionics and electronic warfare systems, communication-electronics operations staff officer, and avionics maintenance staff officer. After receiving his master of science degree in logistics management from the Air Force Institute of Technology, Squadron Leader Trichlin will take up an appointment in the Directorate of Maintenance Planning of the Australian Department of Defence Air Force Office.

Captain Robert E. Trempe graduated from the University of California at Los Angeles with a bachelor's degree in bacteriology, and received his commission through the Air Force Reserve Officer Training Corps in 1973. After completing basic transportation officer training, Captain Trempe was assigned to Langley AFB, Virginia, where he was chief of the base passenger and freight terminals and served as transportation requirements analyst for the Headquarters United States Air Force-sponsored Support of Mobility Automatic Data Processing Requirements Study. In September 1975 Captain Trempe was reassigned to the 60th Aerial Port Squadron where he served as plans and programs officer. In January 1977 he was assigned to the 611th Military Airlift Support Squadron, Osan Air Base, Korea and served as Officer-in-Charge, Air Freight Services. In March 1978 Captain Trempe was assigned to Headquarters, Twenty-First Air Force, McGuire AFB, New Jersey as Chief of the Air Reserve Forces Aerial Terminal Branch. Captain Trempe left this assignment to attend the Air Force Institute of Technology at Wright-Patterson AFB, Ohio. After receiving his Master of Science Degree in Logistics Management, he will be assigned to the Directorate of Transportation, Headquarters United States Air Forces in Europe, Ramstein Air Base, Germany.